3 1761 05234736 6

c/2

a

BOOKS BY J. ELLARD GORE, F.R.A.S.

THE STELLAR HEAVENS: An Introduction to the Study of the Stars and Nebulæ. Crown 8vo, cloth, 2s. net.

STUDIES IN ASTRONOMY. With 8 Illustrations. Crown 8vo, cloth, 6s.

ASTRONOMICAL ESSAYS. With 6 Illustrations. Crown 8vo, cloth, 6*s*.

BOOKS BY CAMILLE FLAMMARION

POPULAR ASTRONOMY: A General Description of the Heavens. Translated by J. Ellard Gore, F.R.A.S. With 3 Plates and 288 Illustrations. A New Edition, Revised, with an Appendix bringing the Work up to 1907. Medium 8vo, cloth, 10s. 6d.

THUNDER AND LIGHTNING. Translated by Walter Mostyn. With Illustrations. Crown 8vo, cloth, 6s. net.

London: CHATTO & WINDUS, 111 St. Martin's Lane, W.C.

ASTRONOMICAL ESSAYS

ASTRONOMICAL ESSAYS

HISTORICAL AND DESCRIPTIVE

BY

J. ELLARD GORE, F.R.A.S.

MEMBER OF THE ROYAL IRISH ACADEMY
CORRESPONDING FELLOW OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA
HONORARY ASSOCIATE OF THE ASTRONOMICAL SOCIETY OF WALES, ETC.

AUTHOR OF "THE SCENERY OF THE HEAVENS," "THE VISIBLE UNIVERSE,"
"THE WORLDS OF SPACE," "STUDIES IN ASTRONOMY," ETC.

WITH 6 ILLUSTRATIONS

LONDON
CHATTO & WINDUS
1907

UNIVERSITY OF TORONTO LIBRARY

106355
17/11/10

Ex umbris et imaginibus in veritatem

All rights reserved

PREFACE

Of the essays included in this volume, the following have appeared in *Knowledge:* "The Brightness of Starlight," "Stellar Brightness and Density," "Holes in the Heavens," "The Stellar Universe," "A Possible Celestial Catastrophe," and "The New Cosmogony;" and the following in *The Observatory:* "The Secular Variation of Stars," "The Number of the Visible Stars," and "The Satellite of Sirius." The rest have not been hitherto published. For much of the information contained in the first three essays, and in Nos. 7 and 8, I am indebted to Houzeau and Lancaster's "Bibliographie Générale de l'Astronomie," vol. i., Introduction. For the illustrations, my best thanks are due to Professor Barnard, D.Sc., of the Yerkes Observatory (U.S.A.), and to Dr. Max Wolf, of Heidelberg.

J. E. G.

April 1907.

CONTENTS

CHAPTER PAGE

I. PRIMITIVE ASTRONOMY 1

II. EARLY ASTRONOMICAL OBSERVATIONS ... 26

III. EARLY ASTRONOMICAL THEORIES 36

IV. THE OLD GREEK ASTRONOMERS 57

V. PTOLEMY'S DESCRIPTION OF THE MILKY WAY ... 69

VI. THE NAMES OF THE STARS 78

VII. THE EVOLUTION OF ASTRONOMICAL INSTRUMENTS ... 88

VIII. MODERN THEORIES 99

IX. MICHELL'S ASTRONOMICAL VIEWS 112

X. SIR WILLIAM HERSCHEL'S ASTRONOMICAL THEORIES AND OBSERVATIONS 124

XI. THE BRIGHTNESS OF THE SUN 201

XII. THE SECULAR VARIATION OF STARS 204

XIII. THE BRIGHTNESS OF STARLIGHT... 215

XIV. THE NUMBER OF THE VISIBLE STARS ... 222

XV. STELLAR BRIGHTNESS AND DENSITY 226

XVI. THE SIZE OF STELLAR SYSTEMS 240

XVII. THE SATELLITE OF SIRIUS 245

XVIII. "HOLES IN THE HEAVENS" 249

CHAPTER PAGE
XIX. THE MAGELLANIC CLOUDS 257
XX. THE RINGED PLANET 266
XXI. THE STELLAR UNIVERSE 280
XXII. A POSSIBLE CELESTIAL CATASTROPHE ... 290
XXIII. RECENT ADVANCES IN STELLAR ASTRONOMY ... 301
XXIV. THE NEW COSMOGONY 324

INDEX 335

ILLUSTRATIONS

TO FACE PAGE

THE "TRIPLE CAVE" IN AQUILA 253

GREAT NEBULA NEAR ρ OPHIUCHI 255

THE MILKY WAY ROUND θ OPHIUCHI 256

THE MILKY WAY AND NEBULA NEAR π^2 CYGNI ... 309

NEBULOSITY ROUND THE STAR 15 MONOCEROTIS 310

THE SPIRAL NEBULA MESSIER 74 PISCIUM 329

ASTRONOMICAL ESSAYS

CHAPTER I

PRIMITIVE ASTRONOMY

In the early infancy of the nations astronomy held a much more important place in the daily life of the people than it does in our time. Even educated people in these days scarcely realize the necessity which the ancients had of constantly referring to the motions of the celestial bodies for a measure of time. Clocks and watches have now become so common everywhere, we are liable to forget that even in the present day they are regulated by the motions of the stars, and that without astronomical observations navigation could not be carried on, and commerce could not have reached its present flourishing condition. In ancient times, however, when a man wanted to know the "time of day," or the hour of the night, he was obliged to find it from the sky itself; and for this reason most people in those days had some practical knowledge of the celestial motions. In fact, man's attention was originally attracted to the heavens, not by their beauty and mystery, but by the ordinary requirements of everyday life. In this way they came to know the heavens, and to assist them in acquiring this knowledge they divided the stars into groups or constellations, and, perhaps naturally, gave these groups the figures and names of men and animals. These names and figures are still found useful for purposes of identification.

Probably the first thing which attracted the attention of primitive man was the regular recurrence of day and night. To him the day symbolized life, and the night represented death. Some of the ancient races counted the diurnal periods by nights and the numbers of years by winters. Thus the old Indians of North America, when asked their age, used to say, "It is so many winters since I was born." In the Scandinavian mythology the day was supposed to be the daughter of the night. This fancy probably originated from the idea of a primeval chaos, in which there was no light, or, as it is described in Genesis i. 2, "darkness was upon the face of the deep." This method of counting the diurnal periods by nights was in use for a long time in Europe. Our "fortnight," a contraction of fourteen days, is an example of this.

The division of the days and nights into shorter periods—now called hours—was to the ancients a more difficult matter. During the day it was comparatively easy to determine the time approximately by observing the height of the sun and the length of the shadows. But during the night this was not so easy, and the constant change going on throughout the year in the positions of the different constellations, owing to the earth's motion round the sun, must have considerably increased the difficulty. From constant observation, however, the ancients came to know at what time of the year certain constellations or groups of stars—like the Pleiades or Hyades—rose and set, and they could thus estimate approximately the time which had elapsed since sunset. In the book of Genesis—one of the oldest books extant—we find no mention of hours, but merely the time of the day. Thus in chap. xix. 23, we read, "The sun was risen upon the earth when Lot entered into Zoar." And there are other similar passages. It is the same in the poems of Homer and Hesiod. The word "hours" is not mentioned by either Plato or Zenophon. It occurs for the first time at the end of the fourth century B.C. in the writings of Menander, who uses the term *hora*, "hour," and *hemiorion*, "half-hour." In the works of the great Roman writers, such as Cicero, Cæsar, Livy, Tacitus, we find terms which were in use before the hour was adopted. Among these may be mentioned *ante lucem*, "before the day," *ad lucem*, "at the approach of day," *prima lux*, "the beginning of day," etc.

Next to the succession of days and nights, perhaps the most striking natural phenomenon to the ancients would be the phases of the moon. The regularity of their recurrence gives a very convenient division of time. The complete disappearance of the moon (to the naked eye) at the time of "new moon," or conjunction with the sun, formed a well-marked epoch for the ancient observers, and the reappearance of the moon as a crescent in the evening sky was welcomed by them with dances and fires. This custom was continued down to the year 692 A.D., when it was abolished at the third council of Constantinople.

The return of the lunar phases is comparatively so rapid, and they occur with such regularity, that even in primitive times the periodicity of the phenomenon must have been sufficiently obvious to every one. The ancients recognized that the lunar revolution was divided into two parts, the "waxing" and "waning" moon, as they are now called. Pliny speaks of them as *luna accedens* and *luna abscedens.* The phases between the "quarters" and full moon were called *luna gibbosa* by the Romans. Hence our modern term "gibbous." The period of days constituting a lunar month formed the first beginning of a calendar among the ancients. This month consisted of 29 days, corresponding to what is now called the synodical month, or period from one "new moon" to the next. This period is not an exact number of days, its actual length being $29^d\ 12^h\ 44^m\ 2{\cdot}86^s$, but the round number of 29 days was sufficiently close to satisfy the requirements of primitive peoples.

Among the ancients, imagination created various forms supposed to be produced by the markings on the moon's surface. Some saw the figure of a hare or rabbit. The Chinese thought they could make out a rabbit sitting on its hind quarters before a mortar or basin, and holding in its fore paws a pestle, with which it pounded rice! A hare was also imagined by the Hindoos, and also by the Indians of North America. On the monuments of Central America the moon is represented by a jug or spiral shell, from which issues a hare. The ancients, Greeks and Romans, saw the face of a girl. Others saw a man. Shakespeare says

> "This man with lanthorn, dog, and bush of thorn."[1]

Next to the phases of the moon and the lunar month, the regular recurrence of the seasons and the apparent annual course of the sun naturally attracted the attention of primitive man. The varying lengths of the shadows cast by the sun at noon would have indicated the progress of the annual cycle. When the shadows ceased to increase or diminish, the ancients knew that the solstice had arrived. The shortest shadows would mark the summer solstice, or longest day, and the longest shadows the shortest day, or winter solstice. But, of course, the first measurements made of these shadows were very rough. By marking the *direction* of the shadow at sunrise and sunset on a certain day, and then in the following year noting when the direction of the shadow was exactly the same, the length of the year could be roughly determined. In ancient Egypt the heliacal[1] rising of a star was used for this purpose, the brilliant star Sirius being the one generally selected.

---

[1] *Midsummer-Night's Dream,* Act v. Sc. i. line 134. See also *The Tempest,* Act II. Sc. ii. line 131.

In high latitudes the phenomenon of the seasons is very striking, but near the Equator the difference is not so noticeable. The word "annual" is derived from the word *annus*, which again comes from *annulus*, "a ring," a word suggested by the apparent circular motion of the sun in the course of a year. The Greek word ενιαυτος, "a cycle," has the same signification. The seasons were fairly well marked in Egypt (about latitude 30°), and here the institution of the year was of great antiquity. At first the length of the year was supposed to be 360 days, but this was soon corrected to 365 days. This latter period seems to have been known in Egypt so far back as about 3000 B.C. This fact is known from

[1] The rising of a star with the sun, or a little before sunrise, was called the "heliacal rising" of the star.

inscriptions on the ancient monuments, the date of which can be determined with considerable accuracy. The more accurate value of $365\frac{1}{4}$ days seems to have been known to the Chinese in the twenty-fourth century B.C.

The ancients must have recognized at a very early period that the stars always retained their relative positions. Manilius (about A.D. 10) states that in his day the constellations were the same as at the time of Trojan war. The early observers made their observations from the tops of hills. The Chinese still point out the elevation from which the emperor Tcheou-Kong observed the heavens in the twelfth century B.C. In Egypt they observed the stars and made their religious offerings on small hills.

The first groups of stars noticed by the ancients seem to have been the Pleiades and Hyades, the Great Bear, Orion's belt, and the Southern Cross. Owing to the precession of the equinoxes, the Southern Cross was in ancient times visible in more northern latitudes than it is at present. About 5000 years ago it was just visible in the latitude of London when on the meridian. Although some conspicuous groups were noticed in early times, the division of the whole sky into constellations was not accomplished until several centuries later. Homer remarks that the Great Bear is the only constellation which never sets. From this we may infer that the constellations Draco, Cassiopeia, and Cepheus had not been formed in his time. According to the Chinese annals, it was in the reign of Yao, about the twenty-fourth century B.C., that the stars were formed into groups or constellations. At that time the small star 10 (i) Draconis (near α Draconis) was the pole star, and later on α Draconis was the star nearest to the celestial pole. The pole star was called *tien-y* by the ancient Chinese. In the sixth century B.C., Confucius mentions some groups in the work called the Chi-King, among which were stars in Scorpio and Lyra. His commentators speak of stars in Leo under the name of the Red Bird. This probably refers to the red star α Hydræ, which lies south of Leo. In Egypt some of the constellations seem to have been known before the thirteenth century B.C. In the tomb of Seti I. there is a lion surrounded by stars, and near it a bull is depicted, which probably represents Taurus. On the ceiling of one of the rooms in the palace of Ramses Miamon (the Greek Sesostris) figures of animals accompanied by stars are shown in connection with the twelve months of the year, showing that the zodiacal constellations were then known. A further advance is seen in the tomb of Ramses IV. at Thebes, thirteenth century B.C. The zodiacal constellations were, however, formed at a much earlier date—probably as far back as the twentieth century B.C. Among the Hindoos the oldest Vedas—which date perhaps from the eighteenth or twentieth century B.C.—do not mention any constellations except the Great Bear.

The ideas of the ancients with reference to the Milky Way are interesting. Some writers resemble it to a road, and the Iroquois Indians called it "the road of souls." Among the ancient Greeks and Romans they supposed two doors, or places, in the Milky Way where it intersected the Zodiac. By that of Gemini they imagined that the souls entered into the world, and by that of Sagittarius they departed and returned to the gods! The Chinese called the Milky Way the celestial river, *tien-ho*.

Following the discovery of a pole star by the ancient observers came the possibility of navigating ships by its aid. According to Aratus and Ovid, the Phenicians were the first to use the pole star for this purpose. In the Middle Ages the Arabians, when sailing in the southern seas, used the bright star Canopus as a guide.

The primitive observers do not appear to have had any clear idea of the immense distances of the stars from the earth. Homer says that the mountains of Greece reach far beyond the limits of the atmosphere into the ethereal regions, and he seems to have imagined that the starry heavens were not very far beyond these mountain tops! The ancients thought the sky was a solid hemisphere resting on the earth.[1] Other crystal spheres were afterwards added, as we shall see in a subsequent chapter. The earth itself was supposed to be flat, and surrounded on all sides by water, but this idea was soon abandoned by the Greek astronomers. It seems, however, to have survived in Western Europe down to the time of the Crusades; and even at the present day there are a few ignorant people who retain the same primitive idea.

It might be expected that the motions of the planets among the stars would have attracted the attention of the ancients at a very early period. It is therefore very remarkable that for a long time after the constellations were formed, the only planet which seems to have been recognized was the brilliant Venus. It is the only planet referred to by Homer and Hesiod. This shows that the ancients did not make a very careful examination of the starry heavens, and did not accurately determine the positions of even the brighter stars. Saturn might possibly escape the notice of primitive races, but it is not so easy to understand how Jupiter and Mars—which are sometimes very brilliant—could have eluded their observation. Although Venus was known as Lucifer[1] when a morning star, and Hesperus as an evening star, the identity of the two objects was known to Pythagoras (sixth century B.C.). This fact seems also to have been known to the Egyptians at an early date. Pythagoras appears to have known all the great planets (except, of course, Uranus), but he lived some three centuries later than Hesiod. Venus was the only one of the planets known in America when it was discovered by Columbus.

---

[1] See Ps. civ. 3.

The progress of astronomy in primitive times was much retarded by the ignorance of writing. This art began with hieroglyphics, as may be seen on the Egyptian monuments. The Greeks appear to have learned the art of writing by means of letters from the Phenicians. The earliest Greek inscriptions seem to date back to the end of the sixth century B.C. Homer does not mention inscriptions, although he refers to pictures and hieroglyphs.

With reference to the star sphere and its apparent daily rotation round the earth, the idea of a meridian, or great circle passing through the north and south points of the horizon and the zenith, seems to have been at first mentioned by Euclid in the fourth century B.C. The colures are first referred to in the writings of Theon of Smyrna in the second century B.C. Achilles Tatius (fourth century A.D.) was the first to use the term "ecliptic" to designate the sun's apparent path in the sky. The obliquity of the sphere was a subject of wonder to the ancients. Many of the old Greek philosophers, such as Anaxagoras, Empedocles, and Democritus, thought that the celestial pole was originally in the zenith and that the horizon was gradually raised from the north! They supposed that at this time the sun's route, which they thought was originally along the Equator, had become oblique. In the twentieth to twenty-third century B.C. the Accadians seem to have divided the circle of the ecliptic into twelve parts, corresponding to the present signs of the Zodiac. The Chaldean astronomers observed the stars at their settings and risings, that is to say, the last setting visible in the evening and the first rising observable in the morning sky. They constructed calendars showing when these risings and settings would take place, and they found groups of stars which rose and set together. These groups were called *paranatolai* by the Greeks. Hesiod speaks of the heliacal risings and settings of the stars in various places in his works. It was on the principle of these risings and settings that the famous poem of Aratus was based. The paranotellons were used by several of the old Greek astronomers, including Eratosthenes, Hipparchus, Hyginus, and Manilius. At the time of these so-called heliacal risings and settings, the star was of course at some distance from the sun's place. This distance depended on the brightness of the star. From Ptolemy's observations it seems that Sirius first appeared in the morning sky when the sun was still

---

[1] See Isa. xiv. 12.

10 to 11 degrees below the horizon. In China similar observations of the stars seem to have been made at a very early period. In the calendar of Hia, which dates from the twenty-second century B.C., the aspect of the constellations at different times of the year is given.

The division of time into hours was in ancient times different from that in use at present. The time from sunrise to sunset was divided into a number of divisions, and the nights into the same number. Hence the hours of the night were not equal to those of the day, and the length of both varied with the seasons. These unequal hours were used by the Greeks and were marked on their sundials. Their clepsydras, or water clocks, were also adapted to this system. Even the invention of clocks did not at once lead to the modern system of equal hours, and the long and short hours seem to have survived down to even the fourteenth century A.D.

The brightest stars are not scattered regularly over the surface of the sky, and consequently their risings could not give the ancient divisions of time of equal length. In ancient Egypt a calendar found on the ceiling of a royal tomb of the thirteenth century B.C. shows the risings of the stars and constellations for a whole year at Thebes. The Chinese at a very early date seem to have used the method of star culminations, that is, the passage of stars across the meridian. For this purpose they used the stars of the Plough and some stars in Lyra. This method of culmination was also used by Hipparchus, who gives a list of stars suitable for the purpose.

Although Venus was the only planet known in *very* ancient times, all the night planets seem to have been known in Egypt so far back as the thirteenth century B.C., and long before they were known to the Greeks. They were, however, known to Pythagoras, as we have said, in the sixth century B.C.; and at the beginning of the Christian era their movements were followed in all European countries. Among the Assyrians Mercury was called Nebo. Its image was sometimes represented with four wings, referring, perhaps, to its apparently rapid movement in the sky. Venus was called Istar or Astar. She was supposed to be the mother of all beings. Mars was called Nergal, and, as is well known, represented the god of war. He was also called the god of hunting. Images of Mars are rare; one represents him with a sword in his hand and with the feet of a cock. Jupiter was called Merodach, and among the Greeks he was supposed to be the king of all the gods. He was also represented with a sword in his hand. Saturn was called Adar, and sometimes Ninip. He was also called "the powerful," "the master of force," "the destroyer of enemies," etc. He seems to have been the Assyrian Hercules, but among the Greeks he was the son of Uranus. The Hindoos seem to have made an independent discovery of the planets, but not till after the ninth century B.C. The ancient Chinese also appear to have discovered the planets independently. They connected them with the five elements—Mercury with water; Venus, metal; Mars, fire (perhaps on account of its red colour); and Saturn with earth. Venus seems to have been the only planet which they named. They called it *Tai-pi*, which means "very white." Among the most ancient Chinese observations of the planets is one of the position of Mars in Scorpio at the beginning of the sixth century B.C.

In tropical regions the lunar month would have been for the ancients the most important long division of time, but in the temperate zones they soon found that the year was of more importance. An attempt was made to combine the lunar months with the annual motion of the sun, but this was found almost impossible, as the year does not contain an even number of lunations. This difficulty led to three kinds of calendar—those exclusively lunar, which are the most ancient; those purely solar; and the luni-solar, which attempted to combine the two systems. The principle of the lunar calendar was to divide the year into 12 months, these being alternately 29 and 30 days long, which gave a year of 354 days. This being about 11 days too short, the seasons were gradually displaced through all the months of the calendar in the course of a few years. In fact, the period was not a year, but a set of lunations. The solar calendar appears to have been adopted at a very early period by the ancient Egyptians. The regularity of the annual rising of the Nile showed them the existence of a period connected with the sun's annual motion. The heliacal rising of Sirius seems to have been the signal for the beginning of this inundation. The Egyptian month was 30 days, divided into three periods of ten days each, and five added days brought the length of the year to 365 days, which was an improvement, but still a little too short. Some writers on Egyptology think that this Egyptian year dates so far back as the twenty-third century

B.C. This year of 365 days being a little too short, the heliacal rising of Sirius was disturbed in the course of time, and came to occur in all months of the year. It was also displaced by the precession of the equinoxes. In the first century B.C. the year of 365¼ days was adopted at Alexandria.

After the Egyptian calendar, the most ancient seems to have been that of the Accadians. Their year consisted of 360 days without any added days. This was, of course, much too short, and this they tried to correct by adding a thirteenth month every six years. This gave a period of 366 days, which was not so exact as the Egyptian year.

The solar calendar is the most practical of all, and is the one at present in use. It was for a long time based on the Alexandrian year. It was introduced at Rome by Julius Cæsar in the year 44 B.C., and is hence known as the Julian year. Before the time of Cæsar, the year was divided at Rome into four parts—Martius, the spring; Aprilis, the summer; Magus, the autumn; and Junius, the winter. The name January was derived from *Janua*, "a door," because it opened the year. The Janua year of 365¼ days is too long by nearly twelve minutes. The Gregorian calendar corrected this by repressing three days in every period of 400 years. Thus the years 1700, 1800, and 1900 were not leap years, but 2000 will be a leap year, as it is divisible by 400.

In ancient times some nations, while recognizing the importance of the solar year, attempted to reconcile it with the lunations. In Greece, down to the time of Herodotus, they had twelve months of thirty days; but when they found the summer solstice inconveniently displaced, they added a thirteenth month to the year. The Arabians also added occasionally a month to their year of 354 days; but these corrections were suppressed by Mahomet. The Jews used a common measure of the motions of the sun and moon, and thus formed a great year of 600 years, or, more correctly, they found that 219,146 days were equal to 7421 lunations, which is not far from the truth. In 329 B.C. Callippus found that in 27,759 days, or about 76 years, there were 940 synodic revolutions of the moon. This cycle, combined with that of Meton, served to correct the Grecian calendar. In this cycle of 76 years there were 33 years of 354 days, 15 of 355 days, and 28 of 384 days. This gave 499 months of 30 days, and 441 of 29 days—a very complicated system. One of the old Chinese astronomers, so far back as the twenty-second century B.C., seems to have noticed the cycle of 19 years, but in later times —about the second century B.C.—they used a period of 60 years, a cycle which seems to have been also used in India.

The pyramids of Egypt seem to have been erected partly as observatories, partly as temples, and partly as tombs. Those of Sakkara and Dabschur seem to be rather more ancient than those of Ghizeh. They were built in layers of diminishing dimensions. Those of Ghizeh are three in number, the largest that of Cheops (known as the Great Pyramid), that of Chephron (brother of Cheops), and that of Menkaura (son of Cheops)—the Mycerinus of the Greeks. From an astronomical observation found on a papyrus, it appears that the pyramid of Menkaura was built about 3009–3006 B.C. These pyramids are oriented correctly to within a few minutes of arc. In the Great Pyramid, the first inclined passage (inclination about 26°) would have pointed—at the time of its construction — to the then pole star α Draconis at its culmination below the pole. This would fix its date at about 3050 B.C. In the Chaldean pyramids there were seven stages of different colours, which represented the seven "planets." Going from the base to the summit, Venus was represented by a white layer; Saturn, black; Jupiter, purple; Mercury, blue; Mars, red; the Moon, silver; and the Sun, gold. On the top of all was a small temple, dedicated to the divinity in whose honour the pyramid was built. In China they also built pyramids, and the ruins of some of them still remain. The ancient inhabitants of America also constructed pyramids, which seem to have been used both as observatories and temples.

Some of the ancient writers thought that the celestial bodies possessed souls, and were guided by intelligence like human beings. This was the opinion of Thales, Heraclitus, Aristotle, Cicero, Seneca, and Socrates. Cicero says, "To refuse intelligence to the stars, whose order and perseverance are so marvellous, and to which are entirely due the preservation and the life of all beings, is to prove one's self devoid of reason."[1] Even so late as the fourteenth century A.D., Duns Scotus could hardly believe that the stars were not animated. The gods of the Greek mythology had perhaps their origin in these ideas. The sun's apparent course in the sky during the year particularly impressed the ancient observers, and seemed to them to indicate the existence of volition. Some, however, including Anaximenes, Anaxagoras, and Herodotus, thought that when the sun attained its greatest height above the equator in summer he was driven back by the winds and cold of the northern regions—a rather puerile idea, as it appears to us with our wider knowledge. The ancients thought that at sunset the sun descended into the sea, and that it was carried back by the circular river, which surrounded the earth, to the place where it should rise the next morning. Joshua is supposed to have stopped the sun in its course for some hours, and it is related that in China, in the eleventh century B.C., during a battle, the prince of the country of Lou implored the sun to grant him a few more hours of daylight, and that it actually went back about 40°, thus giving him about 2½ hours more in which to vanquish his enemies. Even in later times such events are said to have occurred. It is stated by contemporary historians that at the battle of Schmalkalde, fought by Charles V. on April 24, 1547, the sun was arrested in its course for some time on the horizon. But the historians of this event (?) must have been in some way deceived.

---

[1] *De natura deorum*, Bk. III. chap. 21.

The religion of the Chaldeans was practically a worship of the celestial bodies. They offered incense to the sun, moon, the twelve signs of the zodiac, the planets, and "all the host of heaven."[1] The Pleiades were especial objects of adoration. Vast and splendid temples were erected in honour of these sidereal gods. At the time of Nimrod this form of worship seems to have reached its zenith.

Tammuz, or Adonis, which is mentioned in the

---

[1] Deut. iv. 19; and 2 Kings xxiii. 5.

Bible,[1] was the sun, which seemed to die each year in winter, and rise again in the spring; and most of the other heathen gods were personifications of the sun viewed under different aspects. The gods of the ancient Egyptians had a similar origin. At noon the sun was called Ra, and during the night Osiris, and also Horus. It was the same among the Hindoos. They worshipped the sun, the moon, the stars, the aurora, lightning, etc. The god Mitra represented the sun by day, and Varuna at night. They built great temples in honour of the sun. One of the largest of them is in Orissa. In later times Vishnu represented the sun. He is the great hero of the Sanscrit epic, the Mahabharata. Among European nations, the Thor of the Scandinavians represented the sun, but Odin was their supreme god. The feast of Easter originally represented the resurrection or rising of the sun (Astara) at the spring equinox. The sun was also worshipped as a deity among the ancient inhabitants of America and the islands of the Pacific.

Connected with sun-worship was the worship of the sacred fire. Primitive man naturally connected the idea of fire with the solar heat. Among several ancient nations a sacred fire was kept perpetually burning in their temples. Even among the Jews this custom was followed.[2] Vesta was the goddess of fire at Rome, and the vestal virgins had charge of the sacred fires. In Greece these sacred fires were consecrated to Hestia, which was the Greek name of Vesta. In other places in Italy, and also in Spain and Russia, sacred fires were burnt in ancient times. In Japan, and also in America, these fires formed part of the ancient worship. The Greeks and Romans derived the fire from the sun by means of mirrors—which acted like modern burning glasses. This was usually done at the spring equinox.

---

[1] Ezek. viii. 14.

[2] Lev. vi. 12, 13.

Meteoric stones also formed objects of worship in primitive times. They were worshipped by the Phenicians and others, and were placed in their temples. It seems probable that the image referred to in the Acts of the Apostles (xix. 35) as having fallen "down from Jupiter" was carved from a meteoric stone.

Falling stars or meteors were also worshipped by the ancients. They are referred to by Aristotle, Seneca, and Virgil. The Arabians thought they were fiery stones thrown by angels on the heads of demons, when the latter ventured too near the sky. This idea is mentioned in the Koran, and is referred to by the poet Moore in "Paradise and the Peri," where he says—

"Fleeter than the starry brands
Flung at night from angel hands
At those dark and daring sprites
Who would climb th' empyreal heights."

The formation of the constellations, although commenced at a much earlier period, was not completed before the time of Eudoxus, who was a contemporary of Plato, about the fourth century B.C. In this division of the stars into groups, some stars were left outside and were not included in the constellations. These were called by Ptolemy *amorphotoi*, or without figure. All these are now included in the modern constellations, the old boundaries having been extended so as to enclose them. The first star which seems to have been observed by the ancients was the bright star Capella (α Aurigæ), which was called *dilgan*, "the foundation star." The first observation of it probably dates back to about 2000 B.C.

The identity of some of the Egyptian constellations with those of modern astronomy is doubtful. Their most important constellation seems to have been one called *sahou*, which appears to be identical with our Orion. This was an important group in Egypt, because it preceded and announced the approaching rise of Sirius, which again heralded the annual inundation of the Nile. Aldebaran (α Tauri) was called *ary*, and the Pleiades *chooa*, a word which means "thousands." With reference to this latter word, it is an interesting fact that photography has revealed the existence of over two *thousand* stars in this famous cluster. The Great Bear is referred to in the Book of the Dead.

Among the ancient Hindoos the seven bright stars of the Plough (Ursa Major) represented the seven principal rich men or holy persons who were supposed to live beyond Saturn. The bright star Procyon represented the monkey-god Hanumana, but it is not easy to identify the other constellations of the Hindoo sphere.

The ancient Chinese seem to have had about three hundred groups or constellations. In the time of Yao (about the twenty-fourth century B.C.) the sky was divided into four quarters, and these were distinguished by different colours and animals. The one containing the vernal or spring equinox was represented by a white tiger, and the three others by a red bird (the flamingo), a blue dragon, and a black tortoise, or warrior. Among the stars shown we can identify the stars of the Plough, and α and β of the Little Bear. The Plough, or Great Bear, was represented by a bushel or measure of corn, the tail being the handle of the measure. The Chinese sphere seems to have had an independent origin.

The ancient Arabians had their own sphere of imaginary animals among the stars. The Great and Little Bears seem to have been their most important constellations.

Why the constellations received the names they bear it is not easy to see; their nomenclature seems to have been more a matter of caprice than anything else. The origin of the name Coma Berenices is an example of this. Hyginus relates that this constellation was formed in the third century B.C., in the following way: Berenice, wife of Ptolemy Euergetes (son of Ptolemy Philadelphus), made a vow, when her husband was about to leave her on a military expedition, that if he returned in safety she would cut off her hair and consecrate it in the temple of Mars. Her husband returned, and she fulfilled her vow, but on the following day the hair had disappeared from the temple, and Conon, the mathematician, showed Ptolemy seven stars near the constellation of the Lion which did not belong to any group of stars. These the poet Callimachus formed into a constellation, and called it Coma Berenices. This is referred to by Catullus in the lines—

> "Idem me ille Conon coeleste numine vidit
> E Bereneco vertice Cæsariem."

Some of the names of the constellations have been altered since ancient times. Thus the Lyre formerly represented a sea tortoise, or turtle, with its shell.

The following fable is related by the Persian astronomer, Al-Sufi, in his "Description of the Fixed Stars," written in the tenth century A.D. *Al-abûr* (Sirius) and *Al-gumaïsâ* (Procyon) were two sisters of *Suhaïl* (Canopus). Canopus married *Al-djauza* (Rigel), but having killed his new wife, Canopus fled towards the South Pole, fearing the anger of his sisters. Sirius followed him across the Milky Way, but Procyon remained behind and wept for *Suhaïl* till her eyes became weak. Al-Sufi says that Sirius "is called *Al-abûr*, because it has passed across the Milky Way into the southern region."[1] Now, it seems to be a remarkable fact that the large proper motion of Sirius would have carried it across the Milky Way from the eastern to the western border in a period of about 60,000 years. Possibly the Arabian story may be based on a tradition of Sirius having been seen on the opposite side of the Milky Way by the men of the Stone Age. However this may be, we know from the amount and direction of the proper motion of Sirius, that it must have passed across the Milky Way within the period above stated. The Arabic name *Al-abûr* is not therefore, in this case, a fanciful one, but denotes an actual fact. The proper motion of Procyon is very similar, both in amount and direction, to that of Sirius, and consequently it has been on the eastern side of the Milky Way for ages past; and this agrees with the legend quoted above.

Among the ancients the zodiacal constellations were naturally the most important, as they marked the apparent course of the sun during the year. According to Professor Sayce, these constellations were probably formed by the Accadians in the plains of Mesopotamia, some time between the twentieth and the twenty-third century B.C. These "signs of the zodiac" seem to have been very similar to those known at present. On the Nineveh tablets we find the ram, the bull, the twins, the crab, the lion, the scorpion, an archer with a bow (Sagittarius), a goat with a fish's tail (Capricornus), and a deity pouring water out of a jar (Aquarius). Virgo, the virgin, is not represented, however, nor Libra, the balance. These seem to have been formed in more modern times. In ancient times Libra was included in Scorpio. When the zodiacal signs were first formed, the constellations coincided with the "signs," but, owing to the precession of the equinoxes, these have gradually shifted. Thus the sign "Aries" is now in Pisces, "Pisces" in Aquarius, and so on. There seems to have been no connection between the names of these "signs" and the seasons of the year, or the labours of agriculture. The nomenclature appears to have been quite arbitrary. In the original zodiac of the Accadians, each sign was subdivided into three parts, and as a sign represented 30° of the circumference, each of these subdivisions was 10°. In each of these a particular star was assigned, if a suitable one could be found, and the appearance of this star on the horizon announced the arrival of the corresponding portion of the ecliptic. These subdivisions were of considerable *astrological* importance in ancient Egypt. In Persia and India they had somewhat similar divisions. The signs of the zodiac were also known in China at an early date, but they were probably derived from the Western nations.

---

[1] The same story is told by Albufaragius (thirteenth century), and is probably copied from Al-Sufi's work.

The principal constellations were drawn by Hipparchus on a solid globe. This was preserved at Alexandria, and is referred to by Ptolemy, but it is now unfortunately lost. Engraved stones representing Atlas supporting the heavens on his shoulders have been found, but most of these were on too small a scale to show the constellations satisfactorily. There is one, however, in the Museum of Naples on a large ball of marble. On this sphere the constellations are shown, and many of them can be identified. The date of this sphere is supposed to be about 300 B.C. A similar sphere is preserved in the Museum of Arolsen, and there is a marble planisphere in the Vatican. On the latter may be recognized the constellations Ursa Major and Minor, Draco, the signs of the Zodiac, Canis Major, Hydra, Centaurus, Lupus, and Aquila. Libra, the balance, is shown, and the presence of this zodiacal sign shows that the planisphere cannot date back much farther than the beginning of the Christian era.

While some of the primitive nations had a solar zodiac, others had a lunar one. These have been found among the Arabians, the Hindoos, and the Chinese. The moon's sidereal revolution round the earth being between twenty-seven and twenty-eight days, twenty-eight stars were selected along the moon's apparent path in the sky, corresponding in their intervals as nearly as possible to the moon's motion in twenty-four hours. These spaces were called the "lunar mansions." They probably originated in India. They are mentioned in the Rig-Veda, one of the sacred books of the Hindoos, written about the fourteenth century B.C. These divisions had a great importance in the study of astrology. The stars chosen to mark these "mansions" were generally near the ecliptic, with the exception of some, which were selected on account of their brilliancy, such as Vega and Altair. Some, however, near the ecliptic, did not exceed the fourth magnitude. The effect of precession has, of course, much disturbed the positions of these "mansions" in modern times, but they are now merely names, even in India, and, like the signs of the zodiac, have ceased to be of any practical importance.

CHAPTER II

EARLY ASTRONOMICAL OBSERVATIONS

THE history of ancient astronomy is interesting as showing the gradual development or evolution of the "sublime science." The instruments used for making observations in ancient times were crude and not susceptible of any great accuracy. Still much useful work was done, and many interesting naked-eye observations are recorded in the ancient annals. Some of these, however, seem to be mythical, or rather were calculated, not observed. Such is the prehistoric conjunction of the sun, moon, and the five (then) known planets north of the constellation Orion referred to by the old Chinese astronomers. Many observations were, however, really made. Thus we learn from the Chinese records that in the time of Yao, or about 2300 B.C., there were astronomers officially appointed for the determination of the equinoxes and solstices. For finding the exact time of the solstices—that is, when the sun is at its greatest distance north or south of the celestial equator—they used a gnomon[1] and style, and some of these were of considerable size. The gnomon was also used in ancient Greece, and survived in Europe down to the time of Gassendi.

---

[1] The modern word "gnomon" is derived from the Greek word *γνῶμα*, "a mark or token."

The oldest measure of the solstice of which we have any record seems to have been one made by the Chinese astronomer, Tcheou-Kong, about the end of the twelfth century B.C., in the town of Lo-yang, near the Yellow River. Some of these old Chinese observations were used by Laplace for the purpose of determining the diminution in the obliquity of the ecliptic. It is mentioned by Plutarch and Strabo that at the time of the summer solstice (the "longest day") the sun was in the zenith at the town of Syene (now called Assouan) on the Nile, and that it could then be seen at noon from the bottom of wells. This must have occurred before the tenth century B.C.

Astronomy seems to have slowly developed in Greece, for it was not till 431 B.C. that we read of the first reliable observation—that of the summer solstice made by Meton at Athens.

The observations above referred to were made, as we have said, with a gnomon, but the Incas of Peru used for the same purpose the shadows of two poles cast by the rising or setting sun. They also made observations on the passage of the sun through the zenith towards the end of their summer, at which time they held the greatest religious festival of the year. The columns used for the purpose at Quito were destroyed by order of the Spanish governor, Sebastian Belalcacar.

With reference to eclipses, the most ancient on record are those referred to in the Chinese annals. There are six mentioned in the "Chou-king" of Confucius, who lived in the sixth century B.C., and thirty-six in his book called the "Chun-tsiou." The most ancient of all is one mentioned in the former book. It was an eclipse of the sun which took place in that part of the heavens indicated by the stars π and σ Scorpii—between which the ecliptic passes—on the first day of the third month of autumn, a little after the Emperor Tchong-Kang began to reign. According to chronology, which is, of course, somewhat uncertain at such a distant date, this emperor commenced his reign in the year 2158 B.C. Some chronologists, however, think that this date is about twenty years too far back, and astronomical calculations confirm this opinion. Calculations made by means of Oppolzer's tables show that the eclipse probably occurred in the year 2136 B.C. From this distant date down to the end of the seventeenth century the Chinese annals record 460 eclipses of the sun and some of the moon. A long series of eclipses were also recorded by the Babylonians. The Assyrians also registered eclipses, and those of 929 B.C. and 808 B.C. are mentioned in connection with historical events. These eclipses were used by Ptolemy in forming his theory of the moon's motions. Some of these eclipses were verified by Laplace. A great eclipse of the sun is recorded in which the zone of totality crossed Assyria. Oppolzer has found the date of this eclipse as 762 B.C. The Egyptians also recorded a large number of eclipses, and their records go back to about 1600 B.C. In the Indian work, the "Mahabharata," an eclipse is recorded as having been seen in India, and the date of this has been found by Oppolzer as 1409 B.C.

All the eclipses recorded by the Greeks are of later date. The following are some of the most famous of these eclipses. The eclipse of Thales, which put an end to the war between the Medes and Lydians, about 584 B.C., but the date is rather uncertain; the eclipse of Larissa, when the Persians besieged that town, about 556 B.C.; the eclipse of Ennius, mentioned by Cicero, about 399 B.C.; the eclipse of Alexandria, about 364 B.C.; and the eclipse of Agathocles, which is well established as having occurred on the morning of August 15, B.C. 309.[1] Plutarch mentions an eclipse as taking place about 374 B.C., which terrified the senate of Thebes and the Theban army.

That regular observations were made by the ancient astronomers is shown by the fact that on tablets from Nineveh are found lists of planetary and stellar observations and records of the phases of the moon, etc. Observations have also been found of the star α Draconis, which was in those times the nearest bright star to the celestial pole. The Nineveh tablets date back to the seventeenth century B.C. A Chaldean tablet preserved in the British Museum shows that the passage of the moon through its nodes was carefully observed, indicating that the inclination of the moon's orbit to the plane of the ecliptic was known in those early times, and also the cause of eclipses, which even in these enlightened days seem to be a mystery to many so-called 'educated" people.

It is known that astronomy was regularly studied in China so far back as the twelfth century B.C. In a book called the "Tcheou-li" details are given of the organization for this purpose. There was a chief astronomer, called *foung-siang-chi*, with a number of assistants under him, whose duty it was to observe the stars in their passage across the meridian, and thus fix their places in the sky, as is done at Greenwich Observatory in the present day. Another astronomer, called *pao-tchang-li*, with a number of assistants, discussed these observations and studied the aspects of the planets, especially Jupiter, for astrological purposes. They also predicted eclipses, and reported them to the emperor. Meteorological observations were also made. From the seventh century B.C. the Chinese astronomers recorded the appearance of comets and star-showers. In the great work of Ma-touan-lin, consisting of 100 volumes, there are 45 observations of sun-spots visible to the naked eye. These observations were made between the years A.D. 301 and A.D. 1205. Especially large sun-spots were noted in the years 826 and 832. They also recorded the "new" or "temporary stars" of 1572 (Tycho Brahé's) and 1604 (Kepler's), and also that of B.C. 133, which is supposed to have led Hipparchus to form his catalogue of stars. An occultation of Mars by the moon is noted in the year 68 B.C., and this is the earliest recorded occultation in the annals of astronomy. Between the first century B.C. and the eleventh century A.D. the Chinese astronomers recorded 37 observations of Mercury; and the general accuracy of these observations was verified by the great French astronomer, Le Verrier. One of these observations records the passage of the planet between the stars η and γ Virginis, which lie near the ecliptic, and calculation shows that this actually occurred on September 19 and 20 in the year 155 A.D., thus confirming the accuracy of the Chinese observations. Plutarch relates that an occultation of the star Spica (α

---

[1] *Popular Astronomy*, April, 1905.

Virginis) was observed in the year 282 B.C., and this observation was verified by Encke's calculations.

Almanacs seem to have had their origin among the Assyrians, and later on we find reference to "year books" in Hesiod, Ovid, Virgil, Pliny, and other classical writers. To the usual astronomical information the Chaldean astronomers added predictions of coming events, like "Zadkiel's Almanac" of our own day. The Egyptian tablets examined by Brugsch show the course of the planets in the years 105 to 133 A.D., predicting their exact places in the sky, even when near the sun. In one of these interesting tablets a conjunction of Jupiter and Saturn is referred to in the constellation Aries. This seems to have occurred in the year 120 A.D. Even at the present day the Hindoo Brahmins publish almanacs showing in advance eclipses and the positions of the planets, which they calculate by rules given in one of their ancient books. The Mexicans prepared wheels for several years in advance which answered the purpose of almanacs.

Before the invention of clocks and watches there were various methods of measuring time. The first that seems to have been used was the length of shadows thrown by the sun. We learn from Aristophanes that even in his day the time was measured by the length of the shadow cast by a gnomon like the style of a sundial. These gnomons were placed on a pillar, and concentric circles were drawn round the base of the pillar, thus indicating roughly the hour of the day. This method was used by the Chinese, who, as we have seen, used the gnomon for observing the time of the solstices so far back as the twelfth century B.C. In the seventeenth century A.D. the people of Madagascar used this method, which they learned from the Arabs, and for a standard they employed the length of a man's shadow.

According to Herodotus, the Chaldeans were the first to make use of sundials, but they seem to have been also used by the Egyptians in very early times. In the third century B.C. the Chaldean priest Berosus invented an instrument in which the shadow fell on an inclined concave semicircle. One of these was discovered in some ancient ruins near Rome. Another was found in the ruins of Pompeii in the year 1854. Some of these old sundials are preserved in the British Museum, the Louvre, and the Museum at Naples. The reference in the Bible to the shadow on "the dial of Ahaz" shows that sundials were in use among the Jews in ancient times. They were also used at Athens so far back as 434 B.C., but they do not seem to have been known in Rome until the year 292 B.C.

For the correct adjustment of these gnomons and sundials it was, of course, necessary to draw a line exactly due north and south—a meridian line, as it is now called. This the ancients seem to have been able to do with remarkable accuracy. The Great Pyramid of Ghizeh is oriented with great precision, with an error of certainly less than a quarter of a degree; and it is said that in the old pyramids of Mexico and Yucatan, the error did not exceed 1°. The ancient Chinese attached great importance to the observations of stars crossing the meridian, or culminations as they are called, and seem to have determined the direction of the meridian by measurements of shadows at the rising and setting of the sun.

For measuring the hours the Greeks and others used clepsydras, or water clocks. They were also used by the Chinese at an early period, and are described in their book the "Tcheou-li," which dates back to the twelfth century B.C. This instrument consisted of two vessels—an upper one, in which water was kept at a nearly constant level, and with a hole in the bottom, through which the water ran into a lower vessel. In this lower vessel was a graduated vertical rod, the divisions on which represented about fourteen minutes of time. Another form of clepsydra consisted of a metal cup with a small hole in the bottom, floating in a vessel of water. Some of these were regulated so as to fill in about 22½ minutes. Clepsydras are still used in some parts of Asia. They were also used in ancient times in Egypt and Chaldea, probably so far back as the sixteenth or seventeenth century in Egypt. One made in Alexandria was constructed to go for a year! In more modern times we read of one being sent to Charlemagne by the Persian caliph, Abdullah, and one received by the Emperor Frederic II. from the Sultan of Egypt, Malek-al-Kamel.

The ancients found observations of the sun very difficult, owing to its excessive brightness. Archimedes measured its diameter when rising. Seneca speaks of the use of smoked glasses. He also mentions that he observed the phases of a solar eclipse by reflection in a surface of oil or pitch A tub of water was for a long time used in Europe for the same purpose. The old Chinese astronomers measured the altitude of stars on the meridian by means of a tube mounted on a movable axis. The inclination of this tube to the horizon gave the required altitude. This method was also used by the ancient Hindoos, the tube being attached to the style of a gnomon.

For the measurement of angles the Greeks divided the circumference of the circle into 360°, evidently derived from the approximate number of days in the year, and this division has survived to the present day. The Chinese, however, divided the circle into $365\frac{1}{4}°$, and this division is found in their work the "Tcheou-pey," which was written about the time of Hipparchus, a little before the beginning of the Christian era. The "spheres" of Archimedes, Hipparchus, and Ptolemy consisted of two rings, having the same centre, but the plane of one at right angles to the plane of the other. The inner ring was fixed in the plane of the meridian, and the other in the plane of the equator. The time of the solstice was determined by the shadow of the upper half of the equatorial ring falling on the lower half. Sometimes movable circles were added for the ecliptic and solstitial colure. The astrolabe of Hipparchus represented in principle our modern equatorial telescope. It had an hour-circle and a circle of declination. With these were connected two other circles, one representing the ecliptic and the other the solstitial colure. These circles were about eighteen inches in diameter. This gave about one-sixth of an inch to each degree, but, nevertheless, the longitudes of Hipparchus are sometimes in error to the extent of 2°. One of Ptolemy's instruments was a regular mural circle. Another was in the form of a right-angled triangle, of which the sides were fixed one horizontally and the other vertically, while the third side, or hypotenuse, was movable, and could be pointed to the moon when on the meridian. The altitude could then be found by measuring the horizontal and vertical sides. Similar instruments seem to have been used by the Chinese at the end of the second century B.C.

For finding a level surface the ancient observers used plumb-lines from a very early date. These are depicted in the Egyptian hieroglyphics, and were similar in shape to the modern triangles used by masons. They are mentioned by Homer in the Odyssey, and were used by the Grecian astronomers and architects.

The ancient observations in the library of Nineveh were recorded on tablets of clay, on both sides, and were numbered like the pages of a modern book. These were afterwards baked in an oven to render them durable. A number of these clay tablets were collected by Layard, and are now preserved in the British Museum. Plato wrote his works on sheets of wax, and these were afterwards copied on parchment by one of his pupils. Alexandria was for some centuries before the Christian era the centre of intellectual life. Its famous library contained a large number of books collected by Aristotle and Theophrastus, which were sold by Nebus to Ptolemy Philadelphus. This wonderful library was destroyed by fire in the fifth century B.C., and its destruction was an irreparable loss to the history of astronomy.

CHAPTER III

EARLY ASTRONOMICAL THEORIES

> "When they come to model heaven
> And calculate the stars, how they will wield
> The mighty frame; how build, unbuild, contrive
> To save appearances; how gird the sphere
> With centric and eccentric scribbled o'er,
> Cycle and epicycle, orb in orb."[1]

At the time of the destruction of the Alexandrian library, the Greek astronomers had arrived at certain theories of more or less accuracy with reference to the apparent motions of the heavenly bodies. These theories were based on observations made during several centuries by the Egyptians, Chaldeans, and Chinese, and some account of these theories may prove of interest to the general reader.

The cause of the moon's phases naturally excited the curiosity of almost all ancient nations. These phases were previously explained by the old astronomers. The Babylonians at first explained them by supposing that the moon had a bright side and a dark side, that is, that one hemisphere was luminous and the other dark, and these were presented to us alternately by the effect of rotation. It seems curious that they did not notice the fact—which now seems obvious—that the phases depend on the position of the moon with reference to the sun. The Greeks submitted the problem to a mathematical investigation, and of course arrived at a correct solution. From the form of the moon's "terminator," or the boundary between the bright and dark parts, Aristotle came to the conclusion that our satellite is a dark body of spherical form; and the attempt made by Aristarchus to measure the relative distances of the sun and moon show a complete understanding of the laws of illumination of a spherical body shining by reflected light.

---

[1] Milton's "Paradise Lost," viii. 79–85.

An elongation of 15° from the sun was fixed by the Horapolla[1] as necessary for first perceiving the lunar crescent after conjunction with the sun, or "new moon." The moon's "age" would then be about 26 or 27 hours. Schmidt of Athens saw the crescent moon, under the most favourable conditions, between 25 and 26 hours after new moon, and the close agreement of these ancient and modern results is interesting.

More accurate observations of the lunar surface soon abolished the purely imaginary figures which the older astronomers fancied they saw in the moon. Plutarch, in an interesting account of the moon's appearance—which was translated into Latin by Kepler—says that the most obvious spot on the moon's surface is one which he calls the Gulf of Hecate. This seems to be identical with the dark spot now known as Mare Crisium, which is the most conspicuous marking visible during the daytime when the moon is at some distance from the sun.

---

[1] The Horapolla was a work on hieroglyphics. It is a Greek translation from the Egyptian by Phillipus. The writer probably lived about the beginning of the fifth century A.D.

Two other spots are referred to by Plutarch, but it is difficult or impossible to identify them. Some of the ancients thought that the spots were due to the reflection of features on the earth from a surface resembling a badly polished mirror. This theory was maintained by Clearchus among the Greeks, and, according to Humboldt, is still believed in by the modern Persians. Plutarch, however, seems to have thought the spots were really inherent in the moon.

The "earth-shine" visible on the dark part of the moon when in the crescent phase seems to have greatly puzzled the ancient astronomers. Posidonius thought that it might be due to sunshine passing through the body of the moon, which, according to this theory, would be semi-transparent. The correct explanation was not arrived at until the fifteenth century.

The study of the moon's path in the sky of course led the Greeks not only to an explanation of the phases, but also to that of eclipses. But the earlier writers held some absurd theories with reference to eclipses. For example, Anaximander thought that the light from the sun and moon came through a hole, and that when an eclipse occurred this hole was temporarily closed. Others thought that, when eclipsed, the sun and moon left the sky for a little and descended to the earth—a still more ridiculous idea. It was with reference to this latter idea that the Greeks called eclipses *καθαίρεσις* (a pulling down). We first meet the word *εκλειπσις* in Thucydides' history of the Peloponnesian war. It seems, however, that in very early times the Assyrians, Chinese, and Hindoos understood the cause of eclipses, and they were even predicted by the Hindoos and Egyptians with some approach to accuracy. This prediction was accomplished by the Greeks by means of the cycle known as the Saros, a period of about eighteen years. The observations of a long series of eclipses led to the discovery that at the end of 223 lunar months, or about 6585⅓ days, eclipses of the moon return in the same order, and nearly of the same magnitude; but a small difference between the true period and the assumed one somewhat disturbed the accuracy of the predictions. The same remark applies to eclipses of the sun, but the Babylonian astronomers only attempted to predict lunar eclipses. The Chinese also recognized a certain law in the recurrence of eclipses, but sometimes failed in their prediction. For these failures the official astronomers were punished. It is related that in the twenty-second century B.C. the Chinese astronomers Hi and Ho were executed because they failed to announce a great eclipse of the sun which occurred about that time. A period triple the length of the Saros, or 19,756 days, was called by the ancients *exeligmos*, but according to Hipparchus, it would be necessary for greater accuracy to extend the period to 126,007 days, or about 345 years. This contains 4267 lunar months. In the Assyrian inscriptions there is a reference to a cycle of 1805 years. This was probably arrived at, not from observations, but from a knowledge of the periods of revolution of the earth and moon. This long period has been recently referred to by Mr. A. C. D. Crommelin, who suggests for it the name of Megalosaros. He says it "gives surprisingly accurate results as regards duration of totality, and also as regards the latitude of the track, while the shift in longitude follows a fairly regular law."[1]

Eclipses of the sun have been at all times more easily understood by ordinary people than eclipses of the moon. The darkening of the sun's light by the interposition of the moon's body seems more obvious than the passing of the moon through the earth's shadow. The uncertainty connected with the prediction of solar eclipses in ancient times is shown by the fact that the prediction of one in the fourth century B.C. by Helicon of Cyzichus, which duly took place, was looked upon as a great achievement in those days. Eudemus predicted another; but even in the time of Alexander the Great these eclipses could not be predicted with any certainty.

The Romans were still more backward in their knowledge of eclipses. The prediction of an eclipse by Sulpicius Gallus in the second century B.C.—as related by Livy—seems to be of doubtful historical accuracy. However, in the time of the Emperor Claudius, the Roman astronomers, having acquired more accurate knowledge from the Alexandrian school, attained some skill in the prediction of these phenomena.

One of the greatest difficulties experienced by the ancients in accepting the theory that solar eclipses were caused by the interposition of the moon, was that an eclipse of the sun did not occur at every new moon. This was at last explained when they discovered that the moon's orbit was inclined to the ecliptic. Another phenomenon which puzzled them greatly was the fact that the moon is sometimes—although rarely—seen to be totally eclipsed when the sun is still above the horizon near sunset. Pliny (first century A.D.) describes an eclipse of this sort which he speaks of as a prodigy. Cleomenes (second century) doubted the truth of the observation, but suggested that it might be due to refraction, a theory which we now know to be the true one.

---

[1] *The Observatory*, October, 1901, p. 382.

The ancients noticed that the moon is not wholly obscured by the earth's shadow during total eclipses, and Plutarch remarked that the darkening was less the farther the moon was from the earth at the time of eclipse.

Total eclipses of the sun produced a deep impression among the ancients, especially before their cause was discovered. Plutarch remarked that even during totality there was no absolute darkness, but that a light remained comparable with twilight. He noticed that there was a light round the sun which prevented the darkness from becoming complete.[1] The same phenomenon was previously mentioned by Philostratus in his "Life of Apollonius of Tyana," and this latter notice is probably the earliest reference to the solar corona.

The first ideas of the ancient astronomers with reference to the apparent motions of the celestial bodies were very primitive. At least, so they seem to us with our wider knowledge. They imagined that each celestial motion had a sphere of its own—that is, a crystal sphere—and that each of these spheres rotated separately round the earth. They supposed that the sun, moon, and each of the five planets then known—namely, Mercury, Venus, Mars, Jupiter, and Saturn—had each its separate crystal sphere, to which it was attached! For the fixed stars, they imagined an eighth sphere, and they thought that in their case one was sufficient, because these bodies appeared to move in unison, and did not change their relative positions. These spheres they arranged in order of the velocity of the apparent motions. It was a very natural conclusion that the more rapidly a celestial body moved, the nearer it is to the earth. Even now this principle is applied in estimating the distances of the stars; those having large proper motions being considered as probably nearer to us than those with smaller motions. On this hypothesis they arranged the distances in the following order, Mercury, Venus, the Sun, Mars, Jupiter, Saturn, and the fixed stars. But when they came to observe the occasional retrograde motions of the planets, and the inclination of the lunar orbit to the ecliptic, these motions no longer seemed so simple as they at first imagined, and to explain the apparent irregularities they were obliged to add further spheres for each body. This, of course, made the system a very complicated one.

---

[1] "De facie in orbæ Lunæ," chap. 19, 37–40.

Eudoxus of Cnidus, a friend of Plato, seems to have been the first to fix the necessary number of these concentric spheres. To the moon he assigned three, and to the sun three more. For each of the planets he thought four spheres were necessary, but for the fixed stars he considered that one would suffice. This made a total of 27 spheres. But even this number failed to represent all the observed motions, and Callippus, who came after Eudoxus, found it necessary to add seven spheres more—two for the sun, two for the moon, and one for each of the planets Mercury, Venus, and Mars, thus raising the total to 34 spheres. But again this large number of imaginary spheres was not sufficient to account for motions afterwards detected by further observations, and Aristotle was obliged to increase the number to 55.

A grave objection to these crystal spheres might have occurred to these old astronomers, and that is that the distances of the sun, moon, and planets from the earth were subject to change. In the case of the sun and moon this is evident from the fact that eclipses of the sun are sometimes total, and sometimes annular. The planets also vary much in their apparent brilliancy, a fact which might have suggested, one would think, that their distances from the earth also varied. But these objections were overlooked. Sosigenes[1] seems to have been the first to realize the force of these objections.

A curious result of this theory of crystal spheres was the idea of the ancients about the "harmony of the spheres." They fancied that the rotation of these spheres might produce a sound or musical note. This idea seems to have been held by Pythagoras at the time when only eight spheres were supposed necessary. The musical diatonic scale contains eight notes in its gamut. There should therefore, he supposed, be eight notes emitted by the bodies of the planetary system. Pythagoras thought that the more rapid the motion the higher the note, and since all the spheres were supposed to rotate round the earth in 24 hours, the farthest bodies had the greatest velocity, and the nearest the least. Hence, in the planetary system, Saturn would give the highest note, and the moon the lowest. The fixed stars would, of course, give a higher note still. It has not been accurately determined what note Pythagoras attributed to each body. The Chinese book, the "Koue-yu," mentioned these supposed musical notes; and Job says, "When the morning stars sang together, and all the sons of God shouted for joy" (xxxviii. 7), but this is probably allegorical. They are also referred to in the old legends of India. The fact that these musical notes are inaudible to us was explained by the ancients by supposing that, owing to habit, our ears have become insensible to them. They thought, however, that in moments of absolute silence it might be possible to hear them. These fanciful ideas have now vanished with the crystal spheres on which they were based.

---

[1] This was the astronomer employed by Julius Cæsar to arrange the correction of the calendar, 46 B.C.

The idea of spheres to which the celestial bodies were attached necessitated the conclusion that these motions were uniform. But further observations showed that this was not so. The difference in the length of the four quarters of the year formed by the sun's passage through the equinoxes and solstices was known to Eudoxus, Democritus, Euctemon, Callippus, Geminus, and Hipparchus. They found that these quarters varied in length from $88\frac{1}{8}$ to $94\frac{1}{2}$ days. From this irregularity Ptolemy recognized the necessity of distinguishing between mean time and the time shown by a sundial. They found the same irregularity in the case of the moon. The Egyptians and Chaldeans seem to have noticed the movements of the apsides and nodes of the lunar orbit, and from them the Greeks appear to have derived their knowledge on this subject.

Down to the second century B.C. the knowledge of the Chinese with reference to the celestial motions seems to have been inferior to that of Hipparchus and Ptolemy, but in the third century A.D. we learn from a Chinese work called "Kien-siang" that they knew that the length of the year was slightly less than 365¼ days, and that the moon's motion is not uniform. The irregularity in the sun's apparent motion was not discovered by the Chinese until the end of the fifth century A.D. The discovery was made by a hermit named Tchang-tse-sin, and was the result of thirty years' study of the sky. It has been stated, however, that so early as the sixth century B.C. the Chinese had some knowledge of the synodic periods of the planets, but this knowledge was not ascertained scientifically until a thousand years later.

The astronomical tables used in India in ancient times were zealously guarded by the priests, and could not be obtained for many years. The tables of the "Suriya-siddhanta" seem to have been corrected in the thirteenth century. Laplace thought that the earlier tables were subsequent to the time of Ptolemy.

From allusions made by Ovid, Claudianus, and Martianus Capella, it seems that Archimedes constructed a sort of planetarium in the third century B.C. to represent the motions of the celestial bodies. This was a hollow glass globe, on which the stars were represented by small discs. The sun, moon, and planets were carried on movable supports, and the movements were produced by means of gearing. These motions showed the phases of the moon, eclipses, etc. It was probably driven by water-power. A similar instrument was afterwards constructed by Posidonius, and in the Talmud (about

30 A.D.) an instrument for representing the phases of the moon is mentioned.

Finding that the hypothesis of crystal spheres did not satisfactorily account for all the observed movements of the celestial bodies, the ancient astronomers had recourse to the theory of eccentrics. Thus, in the case of the sun, they supposed that the centre of the apparent solar motion was not in the earth, but at some distance from it. But they considered the orbit to be a circle, not an ellipse. In this way they rather ingeniously accounted for the variation in the sun's distance and velocity. For the moon, however, the case is different, and to account for its motion they imagined it revolving in a small circle, called an Epicycle, the centre of which moved on a larger circle, called the Deferent, the centre of the deferent being at the earth. In the epicycle the motion was supposed to be retrograde—that is, in the direction of the hands of a clock—and in the deferent direct, or planetary motion. The period of revolution in each of these circles was the same. This hypothesis of epicycles and deferents was introduced in the fourth century B.C. In the third century B.C. Apollonius of Perga was the great authority on the subject, and the hypothesis was further elaborated by Hipparchus and Ptolemy. From the observed inequalities in the lengths of the quarters of the year, Hipparchus deduced from this theory the eccentricity of the earth's orbit and found it $\frac{1}{24}$, or 0·041. Its real value is now known to be 0·01677, or $\frac{1}{60}$ nearly. The moon, however, presented further difficulties. To explain the variation known as the "equation of the centre," an epicycle was found to be sufficient, but Ptolemy, finding that the position of the perigee of the lunar orbit was not a fixed point, turned the deferent into another eccentric, the centre of which, placed near the earth, revolved slowly round our globe with the velocity of the lunar apsides. The corresponding epicycle was supposed to make its revolution in a time equal to the moon's anomalistic period. In this way the observed motions were represented to a certain degree of approximation. To explain the oscillation of the perigee, Ptolemy supposed that the epicycle was subject to an oscillation of about 13°. This he called the *prosneusis* of the epicycle. Ptolemy, however, does not seem to have thoroughly understood the law which rules this inequality. His attempts at explaining other inequalities, such as the evection, were not very satisfactory, and he seems to have finally abandoned the attempt to explain all the irregularities in the moon's motion. In fact, ancient astronomy added but little to the theory of the lunar motions, and these motions have become thoroughly understood only in comparatively modern times.

The discovery of the inequality in the moon's motion, known as the "variation," is sometimes attributed to the Arabian astronomer, Abul Wefa, but this claim cannot be sustained, and the discovery seems to have been made by Tycho Brahé in 1601. To explain the variation another circle had to be added. Although the Arabians did not know of the "variation," they did not fail to notice that the moon's latitude is not constant. This fact seems to have been discovered in the tenth century by Hussan-Ali ben Amadjour, but he did not find the law which governed it.

Although the hypothesis of epicycles and deferents represented roughly the moon's position in the sky at a given time, it failed to indicate satisfactorily the varying distances of the moon from the earth. In fact, it made the distance at apogee nearly double the distance at perigee. This, of course, did not agree with the apparent diameters. Albategnius, in the ninth century A.D., computed from eclipses that the diameters varied only from $29\frac{1}{2}'$ to $35\frac{1}{5}'$. And even this was a greater difference than it is in reality. Copernicus recognized this discrepancy between theory and observation, and tried to correct it by adding more circles, but without success. Tycho Brahé also attempted a reconciliation, and with somewhat better success; but the necessary arrangement of circles became at last so complicated and unwieldy that Kepler preferred to abandon the hypothesis, and trust to observations for empirical values of the necessary corrections.

The motions of the planets were also represented by epicycles and eccentrics. Ptolemy used a first eccentric, which was called by his successors the "equant." This was a circle supposed to be described by the centre of the deferent. Heraclides of Pontus, who lived long previous to Hipparchus, seems to have had clear ideas of the motions of Mercury and Venus round the sun. According to his views, the sun was carried on an epicycle, the centre of which corresponded to what is now known as the "mean sun." Round this point the two inferior planets described circles or epicyles which the sun carried with it. Seneca thought that the retrograde motions of the superior planets were not real, but merely apparent.

The approximations obtained by Ptolemy were nearly as exact as observations could be made by the instruments of his day. They would not, however, have agreed with modern measures of precision. Ptolemy thought that the lines of apsides of the planets were invariable, but the old Indian astronomers were aware of the displacement of both the apsides and nodes of the planetary orbits, and the reality of these motions was established by the Arabian astronomers. The latter also knew of the slow diminution in the obliquity of the ecliptic.

Notwithstanding, however, the discoveries they made, the Arabians continued to use the epicycles of Ptolemy, and in fact this was the only practical system in use down to the time of Kepler. It was used as a guide to the motions of the planetary system for about 1500 years. A single exception has, however, been recorded. Alpetragus, an Arabian astronomer who lived in the twelfth century A.D., proposed to replace the epicycles by spirals. But the attempt was not very successful, and was soon abandoned.

The Egyptians and Chaldeans, who were able to predict eclipses, must have had some methods of calculation, but these were probably very rough, and had they been of any real value, the Greeks would most probably have preserved and improved them. The Hindoos and Chinese, who were outside the influence of Greek civilization, seem to have been the only people among the ancients who had independent methods of calculating the celestial motions. Correctly speaking, however, the Chinese had no astronomical theory. Their methods of calculation were empirical, that is, they were founded on observation, and not on theory. They did not trouble themselves as to *why* the planets move as they do, but merely observed the motions, and then formed tables for each planet to enable them to predict their positions in the future. These motions were supposed to be uniform. As the planets have a retrograde motion for some time when near opposition, discrepancies occurred between the predicted and observed places, and this difficulty they could not overcome. Beyond this point they never advanced, and so they remain to the present day.

The most important of the Hindoo books on our present subject is the "Suriya-siddhanta," the author of which is unknown. It is in verse, and is a collection of rules without any theory. By these rules the pundits predicted eclipses and the positions of the planets. But apparently they did not know the reason of these rules, which were expressed in words, and not in the form of equations, as in modern calculations. Even the numbers used were expressed in words, and not by figures, as at present. This added to the obscurity of the method, and made it unintelligible, except to the initiated. Although the methods of the "Suriya-siddhanta" are inferior to those of Ptolemy, they were somewhat more advanced in one point, namely, in the use of sines instead of the chords of arcs. Cosines are also mentioned in this work. The author determined the value of the precession more accurately than Ptolemy did, but he seems not to have known of the displacement of the earth's apogee. He places the equinox near ζ Piscium, which fixes the date of the work at 572 A.D., and this is confirmed by other considerations.

With reference to the real distances of the sun, moon, and planets from the earth, the early astronomers did not arrive at any very definite conclusion. In the third century B.C. Aristarchus of Samos attempted to determine the relative distances of the sun and moon by observations of the moon when in quadrature with the sun, that is, at "half moon." The principle of this method is easily understood. When the moon is in quadrature, the "terminator," or boundary line between the dark and bright parts, should be a straight line passing through the centre of the moon's disc. When in this position the sun and earth, as seen from the moon, subtend a right angle; and then measuring the angle between the sun and moon, we have all the angles of a right-angled triangle, and hence the ratio of the sides. The method is an ingenious one, but is not possible in practice, owing to the difficulty in determining the moment when the moon is *exactly* half full, due to the irregularities of its surface. By this method Aristarchus found the distance of the sun to be only nineteen times that of the moon. Further observations, however, led Aristarchus to suspect that the sun's distance is much greater, and we now know that the real distance is nearly 400 times the distance of the moon.

Hipparchus thought he might be able to find the distance of the moon by means of lunar eclipses. If, he argued, the sun may be considered at a very great distance compared with the distance of the moon, then its apparent diameter, as seen from the moon when in opposition, would not differ much from the diameter as seen from the earth at the same moment. And this assumption is not far from the truth. We can then find the length of the earth's shadow, and its observed diameter at any time would give the distance of the point on the axis of the cone at which the shadow would have this diameter. Now, the time occupied by the moon in passing through the shadow, when a lunar eclipse is a central one, gives the diameter of the shadow, and hence we can infer the moon's distance. By this method Hipparchus found the distance of the moon to be $72\frac{1}{3}$ radii of the earth. This number is about 20 per cent. too great, but his attempt shows clearly his genius and originality. Ptolemy having instruments superior to those who preceded him, attempted a direct measurement of the moon's distance. This he tried to do by measuring the moon's altitude above the horizon in different lunations. But he did not allow for the effect of refraction, and so his result was not so accurate as it might have been. Having obtained a value for the moon's distance, Ptolemy thought he might proceed to determine the distance of the sun from the diameter of the earth's shadow. But his observations were not sufficiently delicate for the purpose, and the parallax he found was much too large. Knowing the distances of the sun and moon, their apparent diameters would give, of course, their real dimensions. The ancients estimated the apparent diameters very ingeniously by noting the time taken by the sun and moon in rising or setting. They measured the time by a clepsydra, or water clock, and with the same instrument they measured the length of the day or night, or the time taken by the earth in making one rotation on its axis; or, what comes to the same thing, the time of one revolution of the star-sphere round the earth. Then the ratio between the time occupied by the sun in rising or setting and the total length of the diurnal rotation gave a fraction which represented the apparent diameter of the sun with reference to 360°, the number of degrees in a circle. Thus, if the time taken by the sun in rising or setting is found to be two minutes, then its apparent diameter would be $\frac{2}{24 \times 60}$, or $\frac{1}{720}$ of a complete circle, and $\frac{360}{720} = \frac{1}{2}$ a degree, which is roughly the apparent diameter. This method was used by the Egyptians, and was repeated in Greece by Aristarchus; but it was justly criticized by Hipparchus, who pointed out that the measurement was affected by the angle at which the sun rose above the horizon.

The early astronomers seem to have been much surprised at finding from the lunar parallax that the moon's real diameter was at least one-fourth of the earth's diameter. From this result they saw that the sun, which is so very much farther away, must be enormously larger than the earth. This discovery must have caused quite a revolution in their ideas of the size of the universe.

As to the sun's real size, opinions differed widely among the ancients, as they had no means of accurately measuring its distance. Anaxagoras (about 500 B.C.) thought it might be a fiery stone perhaps about equal in size to the Peloponnesus;[1] but this was objected to on religious grounds as being an insult to the god Apollo, and Anaxagoras' life was only saved through the influence of Pericles. That the sun is considerably larger than the earth was admitted by Archimedes, Aristarchus, Hipparchus, Posidonius, and Ptolemy, but they did not agree as to the probable size.

---

[1] The southern portion of Greece, now called the Morea.

Comets were a source of much wonder to the ancients, and they failed to account for them by the laws of planetary motion. They were, however, carefully observed. The course of the comet of 370 B.C. was described by Aristotle with such accuracy that Pingré was enabled to compute an orbit. Meteors were for a long time considered as having their origin in the earth's atmosphere.

Among the Greeks, Orpheus is said to have been the first to consider the probability of life in other worlds. Heraclides, and all the followers of Pythagoras, considered each star as the centre of a planetary system. The plurality of inhabited worlds was also taught by Democritus and Epicurus, and Plutarch thought it a reasonable hypothesis. Holding these views, they naturally believed that the moon was inhabited, and they thought that probably its animals were larger and its plants more beautiful than ours.

The early astronomers seem to have had some idea of the precession of the equinoxes, but the fact was first definitely established by Hipparchus in 127 B.C. The motion was first indicated by the displacement of the pole star in the course of ages. In the time of Yao (twenty-fourth century B.C.) the star α Draconis was only $2\frac{1}{2}°$ from the pole, and the small star near it, 10 (i) Draconis, was only 1° 46′. This latter star—although only of the 5th magnitude—was considered as the pole star by the ancient Chinese, and they called it *tien-y*. α Draconis was the pole star of the ancient Assyrians. In the time of Hipparchus, the celestial pole formed, he says, a quadrilateral with three other stars. These stars were possibly 31 (Hevelius) Camelopardali, and two others of the 6th magnitude. Delambre, however, preferred α and β Ursæ Minoris and κ Draconis, but these, although brighter, are much farther off. But it was not by these changes of the pole star that the precession was discovered, but by the change in the position of the equinoctial points. Hipparchus, comparing the position of the star Spica (α Virginis) in his time with its recorded position in the time of Timocharis, found that the equinoxes retrograded along the equator, and with wonderful genius concluded that this motion took place round the poles of the ecliptic, and not round the poles of the equator, and that this movement was not a motion of the stars themselves, but a displacement of the sun's path. This was perhaps the most remarkable discovery made by the ancient astronomers. The truth of the discovery was not, however, at first universally admitted. Germinus, Theon of Smyrna, and Cleomedes ignored it, and Proclus actually rejected it as fanciful, because the Egyptians and Chaldeans had not discovered it. Others misunderstood it, and, without any good foundation for their opinion, thought it was an oscillatory motion. According to Theon of Alexandria (father of Hypatia), this oscillation amounted to 8° on each side of a mean position, with a period of 2560 years. The Hindoos, however, believed that the oscillation amounted to 27°. The Arabian astronomers also fell into the same error, and even in the thirteenth century A.D. they believed in a circular motion of the equinoctial points with a radius of 4° 19′, and with an oscillation in longitude of 10° 45′ in a period of 4000 years. Even Copernicus believed in something of this sort, but the oscillatory motion was finally rejected by Tycho Brahé. In China the discovery of the precession was not made until long after the time of Hipparchus. The Assyrian astronomers concluded that the period of precession was about 43,200 years, which is nearly double its real value. The precession is referred to by Virgil in the "Eclogues," and by Dante in the "Inferno." The ancients considered it as a period of restitution in the life of the universe.

With reference to the planetary motions, the Hindoos imagined that at the creation the seven planets were assembled at the zero of Aries, and that at the end of time they will all again be collected in the same spot. This idea seems to have been the origin of the Hindoo *maha-yuga*, or great age of 4,320,000 years. This is 100 times the Assyrian period of precession mentioned above. In China this was called the *chang-yuen*.

CHAPTER IV

THE OLD GREEK ASTRONOMERS

"At non ingenio quæsitum nomen ab ævo
Excidet; ingenio stat sine morte decus."[1]

In the last chapter reference was made to several of the ancient Greek astronomers. The following is a short account of the most famous of these old founders of Greek astronomy. They are given as nearly as possible in order of time.

Thales of Miletus was born about 640 B.C., and died about 562 B.C. He is generally supposed to have been the founder of Greek astronomy. He thought that the stars are fire, that the moon shines by reflected light from the sun, and that at new moon it becomes invisible because its dark side is turned towards the earth. Like most of the ancients, however, he thought that the earth was the centre of the universe—a natural idea, perhaps, in the infancy of science, but an hypothesis long since exploded. He divided the year into 365 days. He calculated the height of the pyramids of Egypt by measuring the length of their shadows. The pyramids were, of course, ancient monuments even in the time of Thales. According to Herodotus, Thales predicted an eclipse of the sun, a phenomenon which duly occurred, and which put an end to the war between the Medes and Lydians; but that this prediction was really made seems doubtful. It also seems dubious whether the eclipse referred to was really a total one, and even the year in which it happened is somewhat uncertain. Thales is also said to have measured the sun's apparent diameter, but his result has not been recorded.

---

[1] Propertius, *Eligies*, iv. 1, 63 (iii. 1, 2).

ANAXIMANDER, also of Miletus, was born 610 B.C., and died in 547 B.C., so that he was a contemporary of Thales, and indeed a disciple of his. It seems doubtful what his astronomical views really were. According to Diogenes Laertes, he believed the earth to be a sphere; but this seems doubtful, as it is not referred to by Aristotle. According to Plutarch, he thought the earth was shaped like a cylinder or column, and that the sun was about equal in size to the earth. Plutarch also states that he constructed a sphere and horoscope and invented the gnomon; but this account does not seem to be reliable.

PYTHAGORAS of Samos was born about 580 B.C., and died about 500 B.C. He studied among the Egyptians, Persians, and Chaldeans. He seems to have known that the earth is spherical. He considered the question of the musical notes supposed to be produced by the planets and constituting the "harmony of the spheres" referred to in the last chapter. Pythagoras recognized that the "evening star" and the "morning star" were one and the same planet, Venus, as we now call it, but in ancient times known as Hesperus when an evening star, and Phosphorus or Lucifer when visible in the morning sky. Pythagoras is said to have died of hunger in his old age.

Philolaus of Croton was a pupil of Pythagoras and a contemporary of Socrates. He thought that the sun was a glass disc, which reflected the light of the universe! He taught, however, that the earth revolved round the sun, like Venus and Mercury. According to Plutarch, the views of Philolaus were adopted by Plato in his old age. Philolaus found the length of the lunar month to be 29½ days, the lunar year 351 days, and the solar year 364½ days.

Anaximenes, also of Miletus, was born about 530 B.C. According to Pliny, he erected the first sundial in Lacedomonia; and according to Theon of Smyrna, he thought the moon shone by light reflected from the sun, and knew the cause of eclipses of the moon. He was succeeded by his pupil,

Anaxagoras, who was born about 500 B.C., and died in 428 B.C. As stated in the last chapter, he thought that the sun was a fiery stone about the size of the Peloponnesus. Like many of the early Greek astronomers, his views were merely based on theory, and not tested by any appeal to observations. He was the first to explain the phases of the moon and her motion round the earth. Among his pupils were Euripides, Pericles, and Socrates.

Democritus. Born about 460 B.C., and died about 361 B.C. He taught that the earth was a globe suspended in space, that the moon had mountains like the earth, that the Milky Way was an immense multitude of stars, and that there is an infinite number of worlds in space. He believed that matter consists of atoms, an hypothesis which agrees with modern theories.

Empedocles (about 450 B.C.) knew the cause of solar eclipses, and that the planets were beyond the moon's orbit. He thought, however, that the sun's distance was only three times that of the moon.

Meton (about 465–385 B.C.) discovered the "metonic cycle" in conjunction with Euctemon.

Plato was born at Athens in 429 B.C., the year in which Pericles died, and he lived till 347 B.C. He was really a geometer, but deserves to be considered as one of the earlier promoters of astronomy, as he proposed to the mathematicians the problem of representing the apparent celestial motions by means of circles. Over the door of his house is said to have been written the motto, "Let no one ignorant of geometry enter here."

Eudoxus of Cnidus, son of Eschinus, was born about 408 B.C., and died about 355 B.C. He was a pupil of Archytas, and probably Plato. He was an astrologer, geometer, physician, and legislator. He had also a great reputation as an astronomer. He made various observations in Sicily and in Asia. He found the length of the year to be $365\frac{1}{4}$ days. According to Archimedes, he estimated the sun's diameter to be only nine times that of the moon. He seems to have written works, which are now lost, on the "Period," the "Contour of the Earth," the "Phenomena," and the "Mirror." A poetical version of the "Phenomena," written by Aratus, is, however, extant.

Aristotle was born in 384 B.C. at Stagira, and was hence called "the Stagirite." He wrote a work on astronomy, which is now lost, but his work on the sky (*περὶ ουρανοῦ*) contains some observations. It chiefly consists, however, of theories on the motions of the celestial bodies. A commentary on this work was written by Simplicius in the fifth century A.D. Aristotle was for some time tutor to Alexander the Great. In his later years he was persecuted on a charge of impiety and condemned to death, but he fled to Chalcis, and died there in 322 B.C. He is said to have observed an occultation of Mars by the moon, and also one of a star by Jupiter, about 357 B.C.

EUDEMUS of Rhodes was a disciple of Aristotle. He wrote a history of astronomy, of which only a fragment remains. He found the obliquity of the ecliptic to be 24°, which was a close approximation to the value it had in his time.

CALLIPPUS of Cyzicus was a pupil of Eudoxus and a contemporary of Aristotle. He formed a lunar period of four metonic cycles diminished by one day. This was called a "callippic," and began 330 B.C. He also wrote a work on the heliacal risings of the planets.

HERACLIDES of Pontus (about 373 B.C.) was a contemporary of Plato. He wrote several works which are now lost. According to Simplicius, he believed that the earth moved in a circle, while the heavens were at rest.

AUTOLYCUS (about 340 B.C.). He wrote two books; one on the moving sphere (Περι κινουμενής σφαῖρας), and the other on the risings and settings of the stars (Περι επιτολων και δυσεων). These are the most ancient of the Greek works on astronomy which have been preserved.

PYTHEAS of Marseilles—one of the Greek colonies—lived in the reign of Alexander the Great, about 330 B.C. He used the gnomon to find the altitude of the sun at the summer solstice (longest day) by means of its shadow. He is said to have observed at Marseilles that on the longest day the height of the gnomon was to the length of its shadow in the proportion of 600 to 209. Allowing for the change in the obliquity of the ecliptic in 2230 years (about 17′ 23″),[1] I find that this observation would make the latitude of Marseilles about 42° 56½′. The correct latitude is 43° 17′ 50″, so that Pytheas' observation was not far from the truth.

EUCLID, the famous geometer, was born about 330 B.C., and died about 275 B.C. He is chiefly known by his "Elements of Geometry," familiar to every schoolboy; but he also wrote a book called the "Phenomena" (*φαινόμενα*), which treats of the risings and settings of the stars. He recognized that the earth is a sphere. He also wrote a work on optics.

TIMOCHARIS and ARISTYLLUS (about 300 B.C.) made some important observations of the positions of stars, which were afterwards used by Hipparchus in establishing his great discovery of the precession of the equinoxes.

ARISTARCHUS of Samos (about 310–250 B.C.). He wrote a work on "Sizes and Distances." He taught that the moon shines by reflected light from the sun, and that the earth rotates on an axis. His attempt to measure the sun's distance from the earth is described in the preceding chapter. According to Plutarch, Aristarchus believed that the sun was immovable, and that the earth revolved round it; but in those times it was dangerous to hold such views, and, like Anaxagoras, he was accused of impiety.

---

[1] The obliquity of the ecliptic in 1900 was, according to Stockwell, 23° 27′ 8·26″, and diminishing at the rate of 0·468″ per annum. Hence the obliquity in the time of Pytheas would be about 23° 27′ 8″ + 17′ 23″, or 23° 44′ 31″.

Aratus was a contemporary of Aristarchus. He wrote works entitled the "Phenomena," the "Diosemia" (Signs and Prognostics), and the "Mirror." He can hardly be called an astronomer, as he seems to have made no observations, and merely versified the work of Eudoxus. In the "Phenomena" he gives a description of the constellations (after Eudoxus). Some of his statements are curious. For example, he says that Lyra only contains small stars, but at present its principal star, Vega, is one of the highest stars in the heavens. He also says that Cygnus contains stars neither large nor small, but one of them, α Cygni, is now but little below the first magnitude, and ϵ and δ are above the third magnitude. Commentaries were written on the work of Aratus by Cicero, Cæsar Germanicus, and Festus Avienus.

brighte

Archimedes of Syracuse was born 287 B.C., and was killed by the Roman soldiers at the capture of Syracuse in 212 B.C. He was a contemporary of Eratosthenes. Although chiefly known as a mathematician—and one of the greatest that ever lived—he also wrote on astronomy. He went to Egypt to instruct the priests of that country, and at Alexandria made the acquaintance of Conon, the geometer, to whom we owe the formation of the constellation Coma Berenices. Archimedes supposed that the sun's diameter was about 300 times that of the moon. This would make it about 648,000 miles. The real value is 866,000 miles, so that Archimedes' estimate was not very wide of the mark. He attempted to measure the sun's apparent diameter, and found it less than 32′ 56″, and more than 27′ 0″. But Archimedes was evidently ignorant of trigonometry, and could not calculate the angle at the vertex of an isosceles triangle when he knew the sides and the base. This ignorance of trigonometry was common to all the ancient astronomers and mathematicians down to the time of Hipparchus. Archimedes is said to have constructed a sort of "orrery" for representing the motions of the celestial bodies.

Eratosthenes of Cyrene was born in 276 B.C. He was appointed librarian of the Alexandrian library by Ptolemy Euergetes. He was the first to measure the size of the earth, and employed the method used at present. He constructed large "armillas," or fixed circular instruments, for making astronomical observations. Most of his writings are lost, with the exception of some fragments. A book called the "Catasterisms" (*καταστερισμόι*), or constellations, is ascribed to him, but the authorship seems doubtful. It contains a list of 44 constellations and 475 stars, but with no accurate positions given. Eratosthenes was also a poet, grammarian, philosopher, geometer, and geographer. Having become blind in his old age, he committed suicide by voluntary starvation in 196 B.C.

Apollonius of Perga in Pamphylia, and hence called Pergæus. He was one of the greatest mathematicians of antiquity. He lived about 250–220 B.C. He wrote a work on conic sections. He seems to have held the theory that the planets revolve round the sun.

Hipparchus, born about 166 B.C., at Nicæa in Bithynia. He was the greatest astronomer of antiquity, and has been called the Father of Astronomy. Most of his observations seem to have been made at Rhodes. Some say that he also observed at Alexandria, but others deny this. He wrote a commentary on Aratus, and this is the only one of his works which has been preserved. He formed a catalogue of the fixed stars, which was afterwards revised by Ptolemy. He discovered the precession of the equinoxes, and investigated the motions of the moon's nodes and apogee, her parallax, eccentricity, equation of the centre, and the inclination of her orbit. He calculated eclipses. He deduced the eccentricity of the earth's orbit, and found the length of the tropical year to within 4½ minutes of the correct value. He was the first to use methods of calculation analogous to modern plane and spherical astronomy, and made a better approximation to the sun's distance than had been previously obtained. Professor de Morgan says of him, "If Hipparchus had possessed the pendulum and telescope, fifty years might have enabled his successors to place astronomy in the state in which it stood at the birth of Newton."

POSIDONIUS, a Stoic philosopher, was born about 135 B.C., and died about 50 B.C. He observed at Rhodes, and constructed a planetary machine, or "orrery." He computed the earth's circumference to be 180,000 stadia. Only fragments of his writings have been preserved.

CLEOMEDES lived in the reign of the Roman emperor Augustus, first century B.C. He wrote a book with the title "Circular Theory of the Celestial Phenomena" (*κυκλικης θεοριας των μετεωρων*). This is, correctly speaking, a work on cosmography, but contains some astronomical researches. He proves that the earth is a sphere, but, like most of the ancients, he thought it was the centre of the universe. He attempted a measurement of the earth's circumference, and gives details. He found from astronomical observations that the distance from Rhodes to Alexandria is about $\frac{1}{48}$ of the earth's circumference, and taking the actual distance as 5000 stadia, the circumference would be 240,000 stadia. The exact length of a "stadium" is not very certain, but assuming it to be about 157·5 metres, or 516·73 feet,[1] this would make the earth's circumference about 23,480 miles, which is a fairly close approximation.

Geminus of Rhodes is supposed to have lived in the time of Cicero, about 70 B.C. He wrote a work entitled "An Introduction to the Phenomena" (εισαγωγη εις τα φαινόμενα). It contains no reference to the "Phenomena" of Aratus, and seems to have been an introduction to astronomy. He mentions the stars which have proper names, such as the Pleiades, Hyades, the Manger and Asses (Cancer), Regulus, Spica, the Fishes, Arcturus, Procyon, Sirius, Canopus, etc. He also gives the names of the northern and southern constellations. From this list we learn that the little constellation Equuleus (ιππου προτομή) was formed by Hipparchus. A note added to the work by an anonymous writer gives the following list of first magnitude stars: Capella, Vega, Arcturus, β Leonis, Aldebaran, Procyon, Betelgeuse, Spica, Rigel, Sirius, Fomalhaut, θ Eridani (the last of the river), Canopus, and Centauri—fourteen in all. Curiously enough, he omits Altair and Regulus, and includes β Leonis. This latter star was also rated first magnitude by Ptolemy, and by Al-Sufi in the tenth century A.D., but it is now a little below the second magnitude; and Altair is fully first magnitude.

---

[1] Dreyer, "Planetary Systems," p. 175.

Manilius lived about A.D. 10. He wrote a poem with the title *'Αστρονομικῶν.*

Menelaus wrote a book on the sphere, and made some astronomical observations at Rome about the year 98 A.D., in the reign of the emperor Trajan. He suggested that the Milky Way is a collection of faint stars.

Ptolemy. His correct name was Claudius Ptolemæus Pelusiniensis. He was an astronomer, mathematician, and geographer. Little is known of his life, but it seems certain that he observed at Alexandria in the years 127 to 151 A.D., during the reigns of the Roman emperors Hadrian and Antoninus Pius, and as he survived Antoninus, he must have been alive in A.D. 161. According to an Arabic tradition, he lived to the age of 78. He wrote several works, including a large one on geography, but his greatest work is the famous one known as the "Almagest." The correct title of this work is Μεγάλη Συνταξας τῆς 'Αστρονομίας. The name *Almagest* is a compound of the Arabic *al* (the) and the Greek μεγίστι (greatest), meaning his greatest work. It was translated from the Greek into Arabic about the year 827 A.D., by Ishak Ibn Houain, by order of the caliph Al Mamun, who then reigned at Bagdad. The emperor Frederick II. had it translated into Latin about the year 1230, and about the year 1350 Girardus of Cremona made a translation of it at Toledo. A translation by Liechtenstein was *printed* at Venice in 1515. The Greek text was printed at Basle in 1528, accompanied by a commentary on it by Theon of Alexandria (fourth century), father of the famous Hypatia. This edition was edited by Simon Grymnæus. A Latin translation from the Greek was made by Trapezuntius (George of Trebizond), and printed at Venice in 1527, and in Basle in 1541 and 1551. A Greek edition, corrected by Halley, was printed at Oxford in 1712. Another Greek edition with a French translation was published by Halma in 1816. This edition was chiefly derived from a ninth or tenth century Greek manuscript preserved in the Bibliothèque du Roi, Paris. Ptolemy's observations were based on those of Hipparchus. But he seems to have made some observations himself, as his description of the Milky Way appears to be original, and also his alignments of certain stars. The inequality in the moon's motion known as the evection was discovered by Ptolemy. This is the largest of the lunar inequalities, and is due to the alternate increase and decrease of the eccentricity of its orbit.

CHAPTER V

PTOLEMY'S DESCRIPTION OF THE MILKY WAY

IN the second chapter of the eighth book of his famous work the "Almagest," Ptolemy gives a description of the Milky Way as he saw it in the second century of the Christian era. As this description is not, I think, generally known, I give his account translated from Halma's French translation of the "Almagest" (from the original Greek), published in 1816 (Tome Second, p. 84). I have identified the stars mentioned by Ptolemy, and give my identification in square brackets. When the meaning of a word seems doubtful, I give the original Greek word used by Ptolemy. Ptolemy says—

"Such is the order according to which we have been able to place the stars. We will add to this description what it is possible to say on the situation of the milky zone, as we have observed in each of its parts, in trying to describe the different appearances.

"In the first place, the Milky Way is not a circle, but a zone, which is almost everywhere as white as milk, and this has given it the name it bears. Now, this zone is neither equal nor regular everywhere, but varies as much in width as in shade of colour, as well as in the number of stars in its parts, and by the diversity of its positions; and also because that in some places it is divided into two branches, as it is easy to see if we examine it with a little attention. The following are the most remarkable details we have found, and those most worthy of observation.

"The double portion of this zone has one of its points of junction near the altar [Ara], and another near the bird [Cygnus]; and of these two branches, the more western or preceding one does not touch the other. For they separate at the points of the altar and the bird (*the hen*) [or Cygnus]. But the following branch touches the rest of the milky zone and forms but a single zone, through the middle of which we can describe a great circle. We will speak of this zone, beginning with the more southern portions.

"These are at the feet of the centaur, but less dense (*ἀραιότερα*) and darker (*ἀμαυρότερα*). The portion which is in the joint of the right hind foot is a little more southern than the northern line of the milky zone, as well as that which is in the left fore knee, and that which is on the right hind ankle [of the centaur]. But that of the shank of the left fore leg is in the middle of the milky part. While that of the same hoof, and that of the right fore hoof [*α* Centauri] are distant, towards the bear, from the southern curve, about two of the 360° of a great circle. They are denser at the hind feet. Then the northern curve of the milky zone is about 1½° from the loins of this animal, and the southern occupies the hearth of the altar and touches the more northern of the two stars which are in the hearth [*β* and *γ* Aræ], and the more southern of the two at the base [θ Aræ]. And the northern star of the hearth [ϵ Aræ], with that which is in the middle, is in the same milky zone, and these parts are much more transparent [ἀραιότερα]. Its northern part includes the three joints placed immediately before the sting of the scorpion [θ, ι, κ Scorpii], and the nebulous cluster [557 Dunlop], which is behind the sting [λ, υ Scorpii]. The apsis or southern curve touches the right hind heel of the archer [Sagittarius] and includes the star of the right hand. That of the southern portion of Sagittarius is outside the milky zone, and that of the point of the arrow [γ Sagittarii] is in the middle. The stars of the northern portion of Sagittarius are also in the milky zone, deviating from each other, and from the apsides or curves, by a little more than 1°, the southern from that of the south; and the northern from the opposite. All which surrounds these three joints is a little thicker [ἠρέμα πυκνότερα], but that which surrounds the point of the arrow is very dense, and appears like a smoke. The following portions are a little more transparent, and extend up to the eagle [Aquila], preserving the same width. The star at the extremity of the tail of the serpent [θ Ophiuchi ?], which is held by the serpent bearer [Ophiuchus], placed in pure air [κείμενος αερι], is distant by a little more than 1° from the preceding curve of the milky zone. But of the bright stars which are below, the two preceding are in the same zone, the more southern being at 1°, and the more northern at 2° distant from the following curve. The following star of those which are in the right shoulder of the eagle [σ Aquilæ] touches the same curve, and the preceding [μ Aquilæ] is included, as well as the preceding bright one of those which are in the left wing [γ Aquilæ]. But the bright one of the back [α Aquilæ ?], and the two which are in a straight line with it, almost touch the same curve. After this the whole of the arrow [Sagitta] is in the milky zone, and the star at its point [γ Sagittæ] is 1° from the curve towards the east, while that of the notch [α Sagittæ] is distant 2° towards the west. The portions round the eagle are a little more loaded [πυκνότερα], and the others are a little brighter. The zone then passes over the hen [Cygnus], and the apsis of the side of the bars and the west is limited by the star of the southern shoulder of the hen [γ Cygni ?], and by the star of the same wing, and by the two of the southern foot.[1] The curve towards the east and south is terminated by the star at the extremity of the southern tarsus [ζ Cygni], and includes the two unformed (ἀμορφώτους) [τ and σ Cygni], which are under the same wing, and are distant about 2°; and the portions which surround this wing are rather full. Those which follow them belong to this zone, and are much denser. They appear to commence another part, for they bend towards the extremity of the other, but leaving a space between them. On their southern side they touch the zone, which we will now describe, and which is very bright at this place of contact. But after this interruption of density, which is near the other part, it commences from the bright star which is in the tail of the bird [α Cygni], and from the nebulous cluster of the northern knee [o^1, o^2, Cygni]. Then these portions curve a little up to the star of the southern knee [ω Cygni ?], preserving their density, which diminishes by degrees to the crown of Cepheus. And the side which faces the bear ends at the southern star of the three in the crown [ϵ Cephei], and at the following of these three [δ Cephei], at which it forms two elevations (ἐξοχὰς), one towards the bear and the east, the other towards the south and east. After which the Milky Way entirely embraces Cassiopeia, except the star at the extremity of the foot [ι Cassiopeiæ]. The southern curve goes up to the star in the head of Cassiopeia [ζ]; and the northern to that which is under the foot of the chair [δ ?], and that on the leg of Cassiopeia [ϵ]. The other stars which surround it are all within the Milky Way, of which the neighbouring portions of the curves form a more rarefied current, and those of the middle of Cassiopeia show a very extended density. Then the right portion of Perseus is included in the milky zone. The solitary star outside the right knee of Perseus limits the northern side, which is more rarefied; but the southern [side], which is more dense, is limited by the bright star which is in the right knee [λ ?], and by the two following of the three southern.[1] The nebulous cluster, which is in the hilt of the sword [χ], the star of the head [τ], that of the right shoulder [γ], and that of the right elbow [η], are included. The quadrilateral of the right [knee], and of the calf of same leg [*d*], is in the middle of the milky zone, but the star of the right heel [*e*] is a little inside the southern side. Then comes the belt of the coachman [Auriga], which appears of less density. The star called the she-goat [Capella] on his left shoulder, and the two on his right arm [ν and θ Aurigæ], almost touch the northern and eastern border of the milky zone. The little star which is above and near the left foot [2 or 4?] limits the western and southern side, and that which is half a degree above the right foot [κ or χ, Al-Sufi] is within the same side. The two close stars of the left arm, called the kids [η and ζ Aurigæ], are in the middle of the zone, of which the milk then passes through the feet of the twins [Gemini], showing itself rather dense and rather extended round the stars which are at the extremities of the feet. The following [26 Aurigæ?] of the three stars in a straight line, which are on the right foot of the coachman, and the following of the two on the club of Orion [χ^3 Orionis], with the northern of the four at the extremity of his hand [f^1 and f^2], limit the preceding extremity of the milky zone. The bright one of the right hand of the coachman [θ Aurigæ], and that of the following extremity of the foot of the following twin [γ, ξ Geminorum], are about 1° within the following border. The others at the extremities of the feet, η, μ, ν, are in the middle of the milky zone. Beyond this, it passes by the little and great dog, leaving the little one [Procyon] rather far to the east, and the great one [Sirius] almost quite outside the milky white, towards the west, for it goes like a cloud which touches the star on the back of that [dog], and also the three following on the neck [θ, μ, γ?]. The solitary star which is above the head of this dog, outside and further off, is nearly 2½° inside the curve towards the east; the milky current is rather rare; it goes then through the ship Argo; the northern and preceding star [ξ], among those which form the armour [ἀσπιδίσκι] of the poop, limits the western curve of the zone. That of the middle of this armour [χ], and the close ones below, as well as the bright one of the deck near the rudder, and the middle one of the three on the keel, touch, or nearly so, the same side. The northern of the three at the foot of the mast limits the curve towards the east. The bright one at the extremity of the gallery is 1° inside the same side. The bright one below the armour in the rudder is 1° outside the same side. The southern of the two bright ones in the middle of the mast [δ ?] touches the same side. The two bright ones of the same section of the keel [γ and χ ?] are about 2° inside the preceding curve. At this place the milky current joins the zone which passes through the feet of the centaur. Its course is rather bright in the ship Argo, but that which surrounds the armour is rather dull, as well as that which surrounds the foot of the mast and the section of the keel.

---

[1] The description here is somewhat obscure.—J. E. G.

---

[1] Here the description is again obscure.—J. E. G.

"Now, the zone of which we have just spoken, forming, as we have said, an interruption near that which clusters round the altar, from which it recommences, includes the first three contiguous joints in the body of the scorpion, and leaves towards the west by a degree outside the curved border, the following star [τ Scorpio] of three which are in the body, but the star which is in the fourth joint [η Scorpii] is found in the open space between the two zones, at a distance nearly equal one from the other, and a little more than one degree.

"Then the preceding zone proceeds, turning towards the east, by a degree of the circle, similarly, and terminates the preceding side of the white or milky part by the star of the right knee of serpentarius [η Ophiuchi], and the following side by the star before the same leg. But the western of those at the extremity of the same foot [36 (A) Ophiuchi] touches the same side. Then the western curve is limited by the star of the right elbow of serpentarius [μ Ophiuchi] and the eastern side by the preceding of two which are at the extremity of the same hand [ν Ophiuchi]. From this place there is a considerable interval (διάλειμμα), caused by the ethereal span, in which are the two stars of the serpent's tail [ζ and η Serpentis] following those of the extremity. All the tortuous and thin part of this zone is a rare and almost ethereal current, except that which includes the three points, which is rather dense.

"After this interruption the Milky Way recommences at the four stars which follow the right shoulder of serpentarius [66, 67, 68, and 70 Ophiuchi]; and the bright solitary one placed near the tail of the eagle [ζ Aquilæ] terminates, in touching it, the curved eastern extremity of this zone, but the opposite curve is terminated by the more distant of the four just mentioned on the side of the bear. From this point the zone becomes brighter and contracts in the preceding portions of the beak of the bird [Cygnus], almost having the appearance of an interruption. But the rest from this beak [β Cygni] up to the breast [γ Cygni] is wider and denser, and the star on the neck [η Cygni] is in the middle of this density. But a rarer portion rises towards the bears from the breast to the star on the shoulder of the right wing [δ Cygni], as well as from the two close stars in the right foot [o^1 and o^2 Cygni]. Thus, as we have said, there is a total interruption between the two zones from the stars of the bird above named to the bright star of its tail" [α Cygni].

As the ancients had probably very keen eyesight, Ptolemy's description of the Milky Way is valuable for comparison with modern observations.

CHAPTER VI

THE NAMES OF THE STARS

THE names by which the brighter stars are known—as least most of them—have come down to us from a remote antiquity. But the original names have been more or less altered to suit the requirements of our English tongue. Some of the ancient Arabic names were long and difficult to pronounce, and these have been curtailed and otherwise modified. An examination of these old names and the changes which they have undergone in modern times may prove of interest to the general reader.

We will first consider the brightest stars in order of brilliancy, beginning with the brilliant Sirius, the brightest of the stellar hosts. The name Sirius is supposed to be derived from the Greek word *σείριος* (*seirios*), which signifies brightness and heat. Professor Max Müller thought that the Greek word might be traced to the Sanscrit *svar* or *suonasirau*. Sirius seems to have been worshipped by the ancient Egyptians under the names of Sothis and Osiris, and the latter name without the initial "O" very much resembles our modern name. The Arabic name for the star was *al-shira al-jamânija*, the bright star of Yémen, or Arabia Felix. Perhaps the word *shira* might, in the course of time, be corrupted into Sirius. It was also known as the "dog-star," from the fact of its rising in ancient times with the sun at the time when the so-called dog-days commenced. The Hebrew name was Sihor. Sirius is supposed to represent the three-headed dog Cerberus, who guarded the entrance to Hades in the Greek mythology. It is first mentioned by Hesiod. The French word *soleil*, "the sun," is supposed to be derived from *Syr-œil*, "the eye of Sirius."

Next to Sirius in brightness is the bright southern star Canopus (α Argûs), which does not rise above the English horizon. The Arabic name was *kânupus*, or, in Greek, κάνωβος. It was also called by the Arabian astronomers *suhaïl*—from the root *sahala*—"that which traverses a plain," referring probably to its low altitude in the Arabian sky, where it would appear to move along the southern horizon. After Canopus, in order of brightness, comes α Centauri, but, so far as I know, this star bears no specific name.

Next to Sirius the brightest star visible in the *Northern* hemisphere is perhaps Arcturus, although it is closely rivalled by Capella and Vega. The name Arcturus is derived from the Greek words ἄρκτος and οὐρά, which signify a bear's tail, so called apparently because it lies nearly in the continuation of the Great Bear's tail. The Arabic name for the star was *al-simak-al-ramih*, "the simak armed with a lance." According to the Persian astronomer Al-Sufi, who wrote a "Description of the Fixed Stars" in the tenth century, the word *simak* means "elevated," referring to the high altitude the star attains above the horizon. Schjellerup, however, thought that the word refers to the brilliancy of the star, and not to its altitude.

The bright star Capella (α Aurigæ) derives its name from the goat or kid which is represented in the arms of Auriga, the waggoner or "charioteer" on the ancient globes and maps. The Arabic name for the star was *al-aijuk*, the meaning of which is doubtful. Schjellerup thought it to be the same as the Greek word *αϊξ*, "a goat." The Arabians called it "the Guardian of the Pleiades." It was also called Dilgan by the ancients.

The name of the bright star Vega (α Lyræ) seems to have had its origin in the Arabic word *vâki*, or *al-nasr al-vâki*, "the falling eagle," the wings of the bird being represented by the stars ε and ζ Lyræ, which form with Vega a little triangle, called by the Arabians *al-atsafi*, "the trivet." But what relation exists between a "falling eagle" and the musical instrument known as a lyre (Persian *al-lura*) is not very clear. Possibly, however, as Schjellerup suggests, the Arabic word *al-schaljâk* (a goose)—also applied to the constellation Lyra—refers to the resemblance in shape between a plucked goose and a Greek lyre. The Greek called the constellation χέλυς, "a tortoise," which also somewhat resembles a lyre in shape.

We next come to Rigel, the brilliant white star in the left foot of Orion. The name is clearly derived from the first word of the compound Arabic name *ridjl-al-djauzâ*, "the leg of the giant" (Orion). It may be here mentioned that the three well-known stars, δ, ε, and ζ Orionis, forming "Orion's belt," were called by the Arabian astronomers *mintakat al-djauzâ*, "the belt of the giant," and the stars forming the "sword" *al-lakat*, "the gleaned ears of corn," and also *saïf al-djabbar*, "the sword of the giant." Perhaps the latter word is the origin of the name *Algebar*, formerly applied to Rigel. Manilius says—

> "Orion's beams! Orion's beams!
> His star-gemmed belt and shining blade,
> His isles of light, his silvery stream,
> And gloomy gulf of mystic shade."

Following Rigel in order of brightness, the bright star Procyon (α Canis Minoris) may be placed. This name is derived from the Greek προκύων, which means the "advanced dog," or the dog which goes before Sirius, the "dog-star," because it rises or appears before Sirius in the morning sky. It was called by the Arabians *al-schirâ al-schâmia*, or "the Syrian Sirius," because it set in the direction of Syria. It was also called *al-schirâ al-gumaïsâ*, "the blear-eyed Sirius," the sister of *suhaïl*, or Canopus.

After Procyon in order of brightness comes the southern star Achernar (α Eridani). This name is derived from the Arabic *âchir al-nahr*, "the end of the river." But the "Last in the River," the ἐσχατὸς τοῦ ποταμοῦ of Ptolemy, is certainly the star θ Eridani, as the description of Ptolemy's star by Al-Sufi clearly shows. θ was rated first magnitude by Ptolemy and Al-Sufi, but it has now faded to the third magnitude.

The red star Betelgeuse is variable to some extent, but at its normal brightness it is not much inferior to Procyon. The name Betelgeuse seems to be derived from the Arabic *ibt al-djauzâ*. It was also called *mankib al-djauzâ*, "the shoulder of the giant."

We next come to Altair (α Aquilæ), a name which is clearly derived from the Arabic *al-nasr al-tâir*, "the flying vulture," a name also applied by the ancients to the whole constellation, of which the Latin name is Aquila, "the eagle."

The red star Aldebaran (α Tauri) derives its name from the Arabic *al-dabarân*, "the attendant or follower," because it follows the Pleiades in the diurnal motion. It was also called *aïn al-tsaur*, "the eye of the bull." It was also known by several other Arabic names, such as *al-fanik*, "the great camel," the other stars, or Hyades, being called *al-kilas*, "the young camels."

Pollux (β Geminorum) is the southern of the two bright stars Castor and Pollux in the constellation Gemini, "the twins." They derive their names from the famous brothers in Greek mythology. Castor (α Geminorum) was called by the Arabians *mukaddam al-dziraïn* and *ras al tanâm*, "the head of the twin." To the two stars they applied the term *al-dzira al-mabsutat*, "the outstretched arm." Pollux is a little brighter than Castor.

Spica (α Virginis)—a word meaning "an ear of corn" (French *épi*), held in the hand of the Virgin. The Arabic name was *al-simâk al-azal*, "the unarmed simak," the meaning of which is not clear.

Antares (α Scorpii) is said to be derived from the Greek ἀντάρες, meaning "redder than Mars." The Arabic name was *al-kalb*, "the heart of the scorpion.' Hence the Latin name Cor Scorpionis.

Fomalhaut (α Piscis Australis). Derived from the Arabic *fum-al-hut al-djanûbi*, "the mouth of the southern fish."

Deneb (α Cygni). This name is derived from the first part of the Arabic name *dzanab al-dadjâdja*, "the tail of the hen," referring to its position in the ancient figure which represented a hen or swan flying towards the south.

Regulus (α Leonis). This name seems to have been first used by Copernicus as the diminutive of *rex*, "a king." Ptolemy called it βασίλισκος. It was named by the Arabians *al-maliki*, "the royal star," and *kalb al-asad*, "the heart of the lion," whence the Latin name Cor Leonis. This star, with η and γ in the well-known "Sickle," the Arabians called *al-dhafîrat*, "the tress of hair," and the whole "Sickle" they resembled to the raised tail of a lion. In the figure of Leo, however, given in Heis' Atlas, the sickle forms the head and shoulders of the lion.

Bellatrix (γ Orionis) means "the female warrior." Its Arabic name was *al-nâdjid*, and also *al-mirzam*.

ε Orionis, called Alnilam, from the Arabic *al-nizhâm*, "the string of pearls," evidently an allusion to the three stars δ, ε, ζ in "the belt of Orion."

ζ Orionis, called Alnitak, from the Arabic *nitâk al-djauzâ*, "the girdle of the giant."

η Ursæ Majoris. This star, which is at the end of the Great Bear's tail, or handle of the Plough, is sometimes called Alkaid or Benetnasch, names derived from the Arabic *al-kaïd*, "the Governor," and the name applied to the four stars α, β, γ, and δ, *sarir banâtnasch*, "the coach of the children of the litter."[1] ε Ursæ is called Alirth, probably a corruption of the Arabic *al-djûn*, "the gulf." ζ Ursæ Majoris is called Mizar, of which the origin is doubtful. Its Arabic name was *al-anâk*, "the little she-goat." Close to Mizar is a small star now called Alcor, but named by the Arabians *al-suhâ*, "the neglected small star," and also *al-schitâ*, "winter," and *al-nuaïsch*, "the little litter." With reference to this little star the Arabians had a proverb, "I show him *al-suhâ*, and he shows me the moon," which seems to imply that it could be easily seen by the ancient astronomers, and was not, as some have supposed, a test of keen eyesight in those days.

---

[1] Litter means "a bier." α, β, γ, and δ formed the bier, and ε, ζ, and η the mourners following the coffin.

β Tauri (formerly γ Aurigæ) is called Nath, a word apparently derived from the Arabic *al-natih*, "the butting," referring to its position on the tip of the bull's horn. Admiral Smyth suggested that this might be the origin of the saying, "Not knowing B from a bull's foot."

Mirfak (α Persei) is derived from the Arabic *al-marfik*, "the elbow," referring perhaps to its position in the well-known curved line of stars in Perseus.

Alhena (γ Geminorum). Perhaps derived from the Arabic *al-hamat*, "a mark made with a hot iron on the neck of a camel," a term applied to the stars γ and ξ Geminorum. These were also called *al-maïsân*, "the star which shines with a sharp light."

δ Canis Majoris is sometimes called Wezea, from the Arabic *al-wezu*, "weight," because it does not rise much above the southern horizon in northern latitudes, as if weighed down.

Menkalinan (β Aurigæ). Derived, according to Admiral Smyth, from the Arabic *menkib-dhi-l'inan;* but this name is not mentioned by Al-Sufi, who calls it *tavâbi al-aijûk*.

Polaris (the pole star), called in the Alphonsine Tables "Abrucaba," the origin of which is uncertain. The Arabic name was *al-djudaï*, "the kid."

α Ophiuchi, Ras al-agne. Evidently derived from the Arabic *râs al-hauvâ*, "the head of Peylle, the serpent-bearer."

Alpheratz (α Andromeda). A name derived from the Arabic *surrat al-farras*, "the navel of the horse." It was also called *râs al-musalsalat*, "the head of the chained lady." α Andromedæ was included in Pegasus by Ptolemy.

Alphard (α Hydræ). From the Arabic *al-fard*, "the solitary one," because there is no other bright star near it. It is also called Cor Hydræ. It is a well-known red star, and is so described by Al-Sufi. The ancient Chinese observers called it "the Red Bird."

Almach (γ Andromedæ). A name perhaps derived from the Arabic *anâk al-ardh*, "the panther."

Hamal (α Arietis), "a sheep." The Arabic name was *al nâtih*. β and γ Arietis were called *al-scharataïn*, "the two marks," because they were near the moon's place at certain times.

Denebola (β Leonis) is a name derived from the Arabic *dzanab al-âsad*, "the tail of the lion." This star seems to have been considerably brighter in former times than at present, for Al-Sufi (tenth century) speaks of it as "the brilliant and great star of the first magnitude which is found on the tail," similar words being used with reference to Regulus. Denebola was also rated first magnitude by Ptolemy. But it is now about one magnitude fainter than Regulus, and below the second magnitude. The Arabians called it *al-sarfa*, "the vicissitude," perhaps with reference to variation in its light.

γ Leonis was called Algeiba, from the Arabic *al-djabha al-asâd*, "the front of the lion."

Algol (β Persei). The famous variable star. The fluctuations in its light were possibly known to the ancient astronomers, as they called it *al-gûl*, "the demon," which suggests that the old observers of celestial phenomena may have noticed some peculiarity in the light of the star.

β Ceti was called Diphda, from the Arabic *al-dhifda al-tsâni*, "the second frog"; the "first frog" being *al-dhifda al-auval*, or Fomalhaut (α Piscis Australis). These old Arabic names seem very fanciful.

Alphecca (α Coronæ Borealis) is a name derived from the Arabic *al-munei min al-fakka*, "the brilliant of the crown," or "the gem of the coronet," as it has been called by recent writers.

β Andromedæ is called Mizar and Mirach. *Mizar* means "a girdle," and *mirach* "a mantle or apron," both names having reference to the old figure of Andromeda, "the chained lady."

Etanin (γ Draconis) is supposed to be derived from the Arabic *râs al-tannin*, "the dragon's head," but this word is not given by Al-Sufi.

Schedir (α Cassiopeiæ) is perhaps a corruption of the Arabic *al-sadr*, "the heart." The star is slightly variable in its light.

Enif (ε Pegasi). From the Arabic *auf*, "the nose" of the horse. It was also called *fum al-faras*, "the mouth of the horse."

ε Boötis, called Tzar, Mizar, and Miræ. The Arabic names were *tâbi al-simâk*, *rajat al-simâk*, and *râjat al-facca*. The modern names are all probably derived from the Arabic word *mizar*, "an apron." It is a fine double star, and the elder Struve called it "Pulcherrima" on account of its beauty.

Alderamin (α Cephir) is evidently derived from the Arabic *al-dzira al-jamîn*, "the right arm" (of the monarch Cepheus).

Scheat (β Pegasi) is perhaps a corruption of the Arabic *said*, "an arm."

Algenib (γ Pegasi) is probably a corruption of the Arabic name *djanâh al-faras*, "the wing of the horse."

β Eridani was called Cursa, from the Arabic *kursi al-djauzâ al-mukaddam*, "the anterior throne of the giant" (Orion), a name given to the stars λ, β, ψ Eridani, and τ Orionis, which form a trapezium close to Rigel, and supposed to form a throne or footstool for Orion.

Chaph (β Cassiopeiæ) is derived from the Arabic *al-kaff al-chahib*, "the tinted hand" (of "the lady in the chair").

Alwaid (β Draconis) is derived from the Arabic *al-avâidz*, "the old camels," a term applied to the stars ν, β, ξ, and γ in the head of the dragon.

Vindemiatrix (ε Virginis) comes from Provindemiator, a name given to this star "because it rises in the morning just before the vintage." The Arabic name was *al-auvâ*, "the crier," perhaps because it announced the coming vintage.

Albirev (β Cygni) is a name of doubtful origin. The Arabic name was *minkar al dadjudja*, "the beak of the hen" (or swan).

There are some other stars which have names derived from the Arabic, but those mentioned above are the most important; and even some of those are fast becoming obsolete. The names of the brighter stars, however, such as Sirius, Canopus, Arcturus, Capella, Vega, Rigel, Procyon, Aldebaran, Spica, Altair, Betelgeuse, etc., will probably live for all time.

CHAPTER VII

THE EVOLUTION OF ASTRONOMICAL INSTRUMENTS

WITH the view of rendering their observations more exact, the Arabian astronomers increased the size of their instruments and built large observatories to aid them in their labours. In the ninth century A.D. one was founded by Albategnius, otherwise called Al-Battani, in the palace of Aractus, or Rakkah, to the north-west of Bagdad. The "Alphonsine Tables" of the moon's motion were based on observations made by Albategnius. A little later another was erected by Ibn Yunis on the hill of Mokatim, near Cairo. It was here that they first attempted to measure time by counting the beats of a pendulum, and of observing the sun by reflection from water. Towards the end of the tenth century Abul Wefa founded an observatory near Bagdad, and followed the planets in their orbits round the sun. In this observatory there was a quadrant of about 20 feet radius, and a stone sextant of 56 feet radius, which was used for observing the meridian altitudes of the sun.

In the twelfth century Gabir ben Aflah, known as Geber, a Spanish Moor, erected an observatory at Giraldi, in Spain. This was the first observatory built in Europe. Later on, about A.D. 1259, a magnificent observatory was founded by Ilskhan-Olagon, grandson of Genghis Khan, at Meragah, near Taurus, and this was the seat of the labours of Nasir-Eddin, who published Astronomical Tables, editions of Euclid's "Elements," and the "Spherics" of Theodosius and Menelaus. In this observatory there were some enormous instuments, and among them a gnomon.

In the fifteenth century the famous astronomer, Ulugh Beigh, founded an observatory at Samarcand. This remarkable man, whose real name was Mohammed Taragai Ibn Shah-rokh Ibn-Timur, was the grandson of the celebrated conqueror Timur-len (Timer the lame)—the Tamerlane of modern stories. The name Ulugh Beigh means "the great lord." [1] Shortly after this the Mongol emperors of India established large astronomical instruments in the principal towns of their empire. These instruments differed but little from those used by Tycho Brahé at the end of the sixteenth century. Tycho Brahé had in his observatory at Uraniburgh four enormous circles, which were as highly ornamental as they were geometrically accurate.

For six or seven centuries all scientific work seems to have been confined to the Arabian astronomers. Little or nothing was done at Rome or Constantinople, and these times have been well called the Dark Ages. On the revival of learning—in the period known as the Renaissance—Europe acquired all its knowledge from the Arabians, and imitated them in their observations as well as in other scientific matters. But if Europeans were the disciples of the Arabians in the twelfth to the fifteenth centuries, they soon went far beyond their teachers.

---

[1] Ulugh Beigh was assassinated by order of his son, Abdallatif, in the year 1449.

At first came the invention of clocks with weights and wheel-work, which replaced the clepsydras, or water clocks, of the ancients. It is often stated that the introduction of clocks was due to Wallingfort in the beginning of the fourteenth century, but this is a mistake. Clocks with wheels and weights are mentioned as having been used in the abbey of Citeaux in the first half of the twelfth century.[1] A clock was erected in Westminster Hall in 1288, and a little after that date clocks were constructed in many places in England. Dante, who died in 1321, alludes to clocks, and Maratori tells us that in the fourteenth century there were clocks in all the chief towns in Italy. In these the hours were sounded from 1 to 24. In Milan there was a clock in the Church of St. Gothard before 1339. Padua had one in 1344. This showed the course of the sun and planets. The clock of Charles V. in Paris dates from 1364, and that of Strasburgh from 1368. A mechanical contrivance for regulating the motions of clocks with weights is said to have been invented by Gerbert, afterwards Pope Sylvestre II. It was somewhat similar in principle to the modern escapement of clocks and watches. One of these old clocks is preserved in the South Kensington Museum, London. Watches are referred to by an Italian poet, Gaspar Vesconte, in one of his poems written towards the close of the fifteenth century. Like all the clocks of those days, they had at first only hour-hands.

For portable clocks and watches it was of course necessary to replace the weights by some other motor-power, and in the year 1674 the spiral spring was introduced by Robert Hooke. In the sixteenth century hour-glasses were used. One of these ran for 24 hours, and lead powder was used instead of sand.

---

[1] Calmet, "Commentaire Litteraire, etc.," vol. i. p. 279.

Walther was the first to use clocks in an astronomical observatory. This was in 1484. Tycho Brahé used four, and took an average. Hevelius succeeded in obtaining the time accurately to about twenty seconds.

The idea of using a pendulum in clocks regulated by an escapement is due to Huygens, who published an account of his invention in the year 1658. This new departure in clock-making met with a warm reception, and after Huygens' invention became known, Hevelius was the first to use it in astronomical observations. The combination of pendulum clocks with telescopes has led to the great accuracy of modern observations.

The ancients seem to have had some idea of optical instruments. A lens used as a reading-glass would naturally be the first thing to be thought of. In the tumulus of Birs-Nimroud ivory tablets have been found engraved with mathematical figures of such delicacy and minute accuracy that it seems impossible to suppose that they could have been executed with the naked eye. And this suspicion has been confirmed by the actual discovery of a quartz lens in the same ruins. For similar purposes the Romans used hollow globes of glass filled with water, which acted as magnifying glasses. The emperor Nero is said to have used a concave lens formed from an emerald to correct his short sight, but it seems more probable that he used it on account of the green colour being good for the eyesight than from any optical advantage it possessed.

The use of lenses made slow progress, but spectacles seem to have been used towards the end of the twelfth century. Combinations of lenses to increase the magnifying power were, however, unknown at this period. These seem to have been proposed by the Italian Fracastor in the first half of the sixteenth century, and about the year 1590 the same inventor hit upon the idea of the compound microscope.

Although the ancients had no knowledge of the principle of telescopes formed by a combination of lenses, they used mirrors for the purpose of divination in their temples, and it is related that in the ancient lighthouse at Alexandria there was a metal mirror in which ships at a distance could be seen more distinctly than with the naked eye—on the same principle as the "front view" reflecting telescope of Sir William Herschel. This mirror is said to have been over a yard in diameter, thus exceeding in size the mirror of Lord Rosse's smaller telescope. A similar mirror is said to have existed at Ragusa in Austria. It does not appear, however, that these mirrors were ever used for astronomical purposes.

Before the invention of the telescope, simple tubes blackened on the inside were used to cut off extraneous light and concentrate the view on distant objects. The advantage of these tubes seems to have been known to Aristotle and Strabo. A tube of this kind is said to have been actually used by Julius Cæsar before his invasion of Britain for examining the coast of England from the heights of Cape Gris Nez. They are also mentioned in the Talmud, written in the first or second century. The ancient inhabitants of America also seem to have used tubes for the same purpose, for they have been found in the old graves of that country. The first of these was found in 1842 in a tumulus at Elisabethtown in West Virginia, and others have since been discovered. They were made of steatite, which is soft and easily worked. These tubes varied from eight to twelve inches in length. The diameter —or "aperture," as it is called in modern telescopes —was about half an inch, and they were contracted near the eye-end to about one-fifth of an inch. That these tubes were used for the purpose mentioned is proved by the fact that a small statuette found in an Indian grave in Bolivia has a tube of this sort in its hand and applied to its eye. These tubes could not have had lenses in them, as glass was quite unknown in America when it was discovered by Columbus.

The principle of the modern telescope seems to have been known for a long time before it was actually applied in practice. Roger Bacon, writing in 1265, describes very clearly the course of luminous rays through lenses, and indicates the arrangement necessary for seeing distant objects magnified. The real invention of the telescope was probably due to some amateur. Glorioso, who succeeded Galileo at the University of Padua, states that Pope Leo X.—who died in 1521—had in his possession a telescope which magnified distant objects. Several attempts to show how telescopes might be constructed were made in the sixteenth century. Among those who wrote on the subject may be mentioned Porta in 1569, John Dee in 1570, and Thomas Digges in 1591.

On October 2, 1608, Lippershay or Laprey, a spectacle-maker of Middleburgh, Holland, petitioned the States-General to grant him a patent for an instrument for magnifying distant objects. Before granting his request, the States-General asked him to construct an instrument which could be used with both eyes, and in reply he sent them a binocular, probably one similar in construction to our modern opera-glasses. Meanwhile, on October 17, 1608, a man named Jacob Metius—otherwise known as Adrianzoon—son of Adrian Metius, Inspector-General of Fortifications, and a well-known mathematician, claimed priority in the invention, and stated that his first attempt was made ten years previously. On February 13, 1609, the States-General considered the claims of these rival inventors, and declined to grant a patent to Lippershay on the grounds that he was not the only one to construct the new instrument. They were, in fact, already being sold by Zeeland opticians. In December, 1608, the French envoy in Holland wrote to Sully that he had made an arrangement with Lippershay to obtain a telescope for King Henry IV., and early in 1609 they were being sold by a goldsmith in Brussels.

In May, 1609, Galileo, being at Venice, heard of the new invention, and from details sent to him by Badovere from Paris, he constructed a telescope. He placed his lenses at the extremities of an organ pipe, and from the tower of St. Mark he showed his friends the powers of the new instrument. Turning his telescope to the sky, he found himself in the presence of wonders of which he had previously no conception. His observations created much interest and astonishment in Europe, and the news of his discoveries spread with wonderful rapidity. The first revelations made by Galileo's instrument were the mountains of the moon, the spots on the sun, the satellites of Jupiter, and the starry nature of the Milky Way. In fact, a new universe was revealed to his astonished vision. His telescopes were made on the principle of the modern opera-glass, namely, with a convex object-glass and concave eyepiece, both being single lens. His largest instrument only magnified about thirty times. Galileo foresaw that his modest instrument would soon be improved on, and that there was practically no limit to the future observations of astronomers.

The invention of the telescope did not at once lead to the improvement of astronomical measurements, and it was not till the years 1622–1633 that Generini suggested that the old alidades might with advantage be replaced by telescopes. This idea was not at first favourably received, and Morin, in ignorance of his predecessor's suggestion, made a similar proposal in 1634. But the only advantage derived from its adoption was an improvement in the definition of the objects observed, and the idea was not of much value until Gascoigne, in 1640, thought of placing parallel wires in the focus of the eyepiece, which could be used in making micrometrical measures. In 1667 Auzout and Picard suggested the use of wires in the form of a cross, the centre of which could be made to mark the optical axis of the instrument. This happy thought added greatly to the precision of astronomical instruments, and, combined with graduated circles, at once enabled astronomers to fix the exact positions of the stars with great accuracy.

The great progress which has been made in accuracy of observation since ancient times may be understood by the following facts. The longitudes of the stars as given by Hipparchus cannot be relied upon as certain within 2°. The Arabian astronomers reduced this error to about four or five minutes of arc. Tycho Brahé's observations were probably accurate to within one minute, and Hevelius attained even greater precision by using simple pinnules. But when telescopes fitted with cross-wires were used in combination with graduated circles, the accuracy was further increased. Bradley's observations are probably correct to within eight seconds of arc, and, at present, observations at Greenwich, Paris, and elsewhere do not probably differ from the truth by even two seconds.

The same may be said of measures of time. Ptolemy could not find the time of the equinoxes to less than a quarter of an hour. In the Middle Ages they reduced this uncertainty to about five minutes, and, with the aid of astrolabes, to about one minute. But after the invention of clocks a closer approximation became possible. Professor Newcomb finds that eclipses observed by Hevelius were correct to within 24 seconds. From the beginning of the eighteenth century observations were possible to within two seconds, and at the present day the exact time of a star crossing the meridian can be observed to within the tenth of a second. These facts show the great progress which has been made since the time of the ancient observers.

When the telescope was first invented, the single lenses used in its construction produced what is known as "chromatic aberration," which gives rise to a fringe of colour round the objects viewed. This colouring interferes with clear vision. To get rid of this imperfection—at least to some extent—the old telescope makers had recourse to instruments of enormous length. Hevelius constructed one of 150 feet in length. Bradley measured Venus in 1722 with a telescope 212 feet long, and Auzot is said to have constructed one of 600 feet, which, however, he could not use, owing to its enormous length.

Sir Isaac Newton made several experiments with a view to the improvement of refracting telescopes —as telescopes with lenses are called—but came to the conclusion that it was impossible to get rid of the chromatic aberration produced by lenses. He then turned his attention to the construction of telescopes with metallic mirrors, and succeeded in making several which gave satisfactory results. In this form of telescope the image, formed by reflection, is free from colour. Newton's telescopes were, however, very small, and only a few of any size were made for about a hundred years, when Sir William Herschel took up the subject and succeeded in constructing several reflecting telescopes of considerable size, his largest being no less than four feet in diameter. This great instrument was finished in the year 1789, and with it the famous astronomer discovered the two small satellites of Saturn, Mimas and Enceladus, and made other remarkable observations. In after years a reflecting telescope of four feet in diameter and 40 feet long was constructed by Mr. Lassell, who took it to Malta, and, with it, discovered numerous nebulæ. These telescopes were, however, soon exceeded in size by Lord Rosse's famous instrument of six feet in diameter, completed in 1845. This great telescope, which is still the largest in the world, is 52 feet in length, and its large mirror weighs about four tons.

Metallic mirrors have in recent years been superseded by mirrors made of glass, ground to the proper curvature and silvered over by a chemical process, the silver film being then polished. These mirrors reflect much more light and give better definition than the old metallic mirrors. There is one of these "silver on glass" mirrors of four feet in diameter in the Paris Observatory, one of five feet diameter was made by the late Dr. Common, and another of five feet has lately been constructed by Mr. Ritchey at the Yerkes Observatory (U.S.A.). Mirrors of even eight or ten feet are now spoken of as possible in the future.

Although Newton despaired of any improvement in refracting telescopes, the problem was not abandoned as hopeless, and in the year 1729, two years after Newton's death, Mr. Chester More Hall succeeded in obtaining a combination of lenses of different kinds of glass which gave an image free from colour. This was the origin of the "achromatic telescope," as it is called, which has made such rapid progress in recent years. The combination of lenses now employed was devised by Peter Dollond in 1758, but the credit of the invention is really due to More Hall.

Further details of the large telescopes of modern times will be found in my book, "Studies in Astronomy" (chap. iii.).

CHAPTER VIII

MODERN THEORIES

"Discipulus est prioris posterior dies."

IN the fourth century A.D., Julianus is said to have thought that the sun, with all the planets, revolved round the earth, that is, that all the planets—except the earth—revolve round the sun, and the system thus formed revolved round the earth as a centre. This was an anticipation of Tycho Brahé's system by more than twelve centuries. But whatever may have been the ideas of the old astronomers, the true theory of the planetary system was not arrived at until Copernicus appeared. At first methods of confirmation were wanting. Even when the "De Revolutionibus" of Copernicus was published in 1543, the truth of the theory rested only on probabilities, and, to confirm its accuracy, it was, of course, necessary to submit it to the crucial test of observation. The retrograde motions of the planets when near opposition were more simply explained by the new theory; but they were also explained with nearly as great accuracy by Ptolemy's system. The idea of motion in simple elliptical orbits had not yet been conceived. Although Copernicus made all the planets revolve round a central ruling body, the sun, he imagined them still to move in the epicycles of the ancients. The old scaffolding had not yet been removed from the temple of Truth, and these antique ideas prevented the heliocentric system from being seen in all its beauty.

After long intervals, however, facts were observed which seemed to afford some partial confirmation of the new theory. At the opposition of Mars in the year 1582, Tycho Brahé made an important observation. He found that the retrograde movement of the planet near opposition agreed with the Copernican theory, while Ptolemy's hypothesis gave an erroneous value of the angular velocity. This notable observation remained for a long time unpublished, and it seems to have been first announced by Möstlin in 1596.

But after the invention of the telescope, evidence in favour of the new theory was rapidly accumulated. The first piece of confirmatory evidence was the discovery of the phases of Venus by Galileo in 1610. These had been predicted by Copernicus in 1543 as a necessary consequence of the revolution of Venus round the sun in an orbit inside that of the earth. Further confirmation was found in the phases of Mercury, which seem to have been seen by Simon Mayer about the year 1615. These observations established the fact that the two inferior planets—that is, those inside the earth's orbit—revolved round the sun.

But still a doubt remained with reference to the superior planets, or those outside the earth's orbit. Here, again, confirmation was afforded by the telescope. The discovery of Jupiter's satellites, which quite evidently revolved round the planet, showed, as it were, a miniature of the solar system itself, and exhibited a sort of "object lesson" as to the construction of the larger system, of which Jupiter itself formed a member. With reference to the motions of these satellites round Jupiter, it was pointed out by Simon Mayer, in 1614, that the motion of any satellite with reference to Jupiter and the sun is uniform, but this is not the case with reference to Jupiter and the earth. This fact suggested that it was the sun, and not the earth, which formed the centre of Jupiter's orbital motion. The satellites of Saturn gave similar evidence in favour of the new theory. The discovery of the progressive motion of light from observations of Jupiter's satellites, announced by Roemer in 1676, was further proof that the sun and earth revolved round each other. But this agreed with the theory of Tycho Brahé as well as that of Copernicus, and further evidence was necessary to decide between the two rival theories. This evidence was at last found in the discovery of the aberration of light by Bradley in 1728, nearly 200 years after the publication of the "De Revolutionibus" of Copernicus. As the aberration of light is due to the earth's motion in its orbit round the sun, this remarkable discovery finally decided the question beyond all doubt, that it was the earth, and not the sun, which moved in an annual orbit. If the earth were at rest, there would be no aberration of light. The Copernican theory was finally adopted as the correct one, and all subsequent observations have tended to confirm it. With reference to the earth's rotation on its axis, this was proved practically by the pendulum experiments of Foucault and Fizeau, recently repeated at Paris; and theoretically by the precession of the equinoxes, which is only consistent with the hypothesis of a rotating globe.

Henceforth the solid spheres and the material epicycles and deferents were consigned to the limbo of ancient myths, and the planets were seen to revolve round the sun in regular curves and in free space, unfettered by any bonds except those of gravitation towards the central body. The conception of the solar system thus freed from the old material shackles gained in simplicity and grandeur. It is to Kepler that this great reform is really due, although, like Copernicus, his views were to some extent anticipated by previous writers. The Arabian astronomer Arzachel, in the year 1080, noticed that of all the planets the motion of Mercury deviated most from a circle, and he supposed that its real orbit was some sort of oval. From similar considerations, Reinholdus, in 1542, even suggested an ellipse as possibly the true form of the orbit. Copernicus also seems to have suspected that the planetary orbits are really elliptical. But these writers had not sufficient observations at their command to confirm the truth of their hypothesis. Kepler, however, having found a series of observations of the positions of the planets made by Tycho Brahé, and extending over a period of twenty years, undertook an examination of the subject. For this purpose he selected the planet Mars, the orbit of which, among the superior planets, differs most from the circular form. By an ingenious and accurate process he traced out the shape of the orbit, and found it to be an ellipse.

The heliocentric revolution of Mars round the sun is nearly 687 days, that is, the period, *as seen* *from the sun*, occupied by the planet in revolving round the heavens from any given star back to the same star again. But seen from the earth—which is also in motion—this period will not be the same. However, if at the end of 687 days we observe the geocentric longitude of the planet—that is, its position as seen from the earth—this second observation, combined with the first, will give the length of the line joining the sun and Mars in terms of the distance of the sun from the earth. From the fine series of observations made by Tycho Brahé, Kepler found the positions for each 687th day after an opposition. In fifteen years the points so found fall in all parts of the orbit, and he obtained eight positions, which gave him a good general idea of the shape of the orbit. This he found was an ellipse with the sun in one of the foci. This was a very remarkable discovery, and constitutes Kepler's first law of planetary motion.

A further effort was, however, necessary to finally upset the old ideas of uniform motion in circles. And this was accomplished in the following way. Kepler found that the sun's apparent diameter was about $\frac{1}{50}$ less in summer than in winter. This could only be due to its being farther from the earth at apogee than at perigee. He also found that the apparent angular motion was about $\frac{1}{15}$ slower when its apparent diameter was least. Following out the motion step by step, he found that the line drawn from the sun to the planet, known as the *radius vector*, swept over equal areas in equal times. All subsequent observations have been found to obey this law, which is known as Kepler's second law of planetary motion.

Following up his investigations, Kepler discovered another and an equally important law. The lengths of the periods of revolution of the planets round the sun increase with their distances from the central luminary. Kepler tried to find whether there was any constant relation between these periods and distances. At first he was much puzzled. He had no analogy to guide him in the search for such a relation, and was obliged to rely on his imagination and inventive genius to find some connection between the two quantities. For a long time Kepler was baffled in his efforts to find the required relation. After many attempts, he at last arrived at the following result: the squares of the periods of revolution are proportional to the cubes of the mean distances from the sun. This is the famous third law of Kepler, and its truth has been abundantly verified by all subsequent observations and researches.

Kepler's laws, combined with the Copernican system, created quite a revolution in astronomical ideas. As it was proved that the distance of a planet from the sun was not constant but variable to some extent, the idea of solid crystalline spheres was no longer tenable, unless the material composing them was supposed to be flexible like indiarubber. Descartes, in his hypothesis of vortices, attempted to make the imaginary spheres fluid. He supposed that the planets are suspended in spherical liquid layers of nearly the same density, which revolve round the sun and carry the planets with it. The spheres being liquid, there would be nothing to prevent small changes in the distance of the planets from the sun. Smaller spheres would, he thought, carry the satellites round their primaries. But he does not explain why the supposed liquid is carried round the sun, and he seems to have overlooked the fact that with the same fluid there would be no variation in the planets' velocity, and that the orbits of all the planets would lie in the same plane. This shows how difficult it is for even men of great genius—as Descartes undoubtedly was—to free themselves from old ideas.

The final blow to the system of the spheres was given by the comets, which were found to cut the orbits of the planets in all directions. It was shown by Tycho Brahé that the comet of 1577, among others, described a large curved orbit round the sun, and that this curve intersected the orbit of the earth and enclosed those of Venus and Mercury. This was confirmed by Borelli, who found that the comet of 1664 was moving in a parabola.

For a long time previous to the advent of Sir Isaac Newton, some of the clearest minds saw that in the great system of the sun and planets a mutual action of some sort probably existed between its members. So far back as the ninth century the Arabian writer, Musa-ben-Shakir, thought that attraction was one of the great forces of nature. Camillus Agrippa, in 1553, thought that all the celestial bodies had an attraction towards each other, and that this action applied to the earth was the cause of the precession of the equinoxes—a remarkable and accurate conclusion. Horrox, well known for his observations of the transit of Venus, writing in 1635, considered the moon as a projectile moved by what he called an emanation from the earth, or, in other words, gravity. Bullialdus, in 1645, went so far as to say that the attraction existed in the sun, and if so, this action should decrease in proportion to the square of the distance. Borelli, in 1666, also said that on the same principle the satellites should revolve in elliptical orbits round their primaries. These views anticipated to some extent the great discovery of Newton; but the authors did not prove their views mathematically, and a rigorous demonstration of the law of gravitation was reserved for Newton.

In 1674 Robert Hooke made some experiments with a conical pendulum in the hope of discovering the cause of planetary motion, and in a letter to Newton he pointed out that the curve described by projectiles under the action of terrestrial gravity is an ellipse of great eccentricity. That attraction decreases as the square of the distance was also the opinion of Wren and Halley. The latter did not succeed in determining the nature of the curve described. He sent his views to Newton, but found that this mighty mind had already solved the problem. Newton's results were soon after published in the famous work known as the "Principia."

Newton's discovery fully explains all the planetary motions, and confirmed the laws of Kepler. If the attraction were inversely proportional to the distance simply, the sun would occupy the centre of the ellipse instead of one of the foci. Newton's discovery not only explains the motions of the planets round the sun, but also the flattening of the earth at the poles, the inequalities in the moon's motion, the libration, the motion of the line of apsides, the motion of the nodes, the moon's nutation, the precession of the equinoxes, and the tides. In mathematical ability Sir Isaac Newton has never been surpassed in the history of the world, and Dr. Johnson said of him, "If Newton had flourished in ancient Greece, he would have been worshipped as a divinity."

As the system of Copernicus was not at first generally accepted, so Newton's discoveries were for some years looked upon with suspicion by his contemporaries. Even the famous Huygens was for a long time opposed to them. It must be admitted that these objections were not altogether unreasonable; for even at the present day the *cause* of gravitation—that is, the method of communication by which a body acts on another at a distance—is as great a mystery as it was in the days of Newton. But the number of applications of gravity shows clearly that the law is correct, although the *cause* of its action remains unknown. All the irregularities of motion observed in the large and small planets, the satellites, and comets, have been found amenable to the law, which seems to be a universal one in nature. Each difficulty which has arisen has only added to it another triumph.

Among the many interesting verifications of Newton's law of gravitation may be mentioned the tides. About 1000 B.C. the Chinese remarked the apparent influence of the moon on the waters of the sea. Indeed, this influence was easily recognized by the coincidence of high tides with new and full moon. It was also known to the Greeks, as—according to Plutarch—Pythias mentioned it in the fourth century B.C., and Seleucus about one hundred years later. Cleomedes, writing in the second century A.D., stated positively that the tides are caused by the moon. The Romans held the same view. Cicero states so distinctly, and Julius Cæsar, speaking in his commentaries of his invasion of Britain, says that when his troops embarked at Boulogne, the tide was high because the moon was full.[1] Pliny seems to have recognized that the sun, as well as the moon, has an influence on the tides. He says, "*verum causa in sola lunâque.*" The connection of the tides with the moon seems also to have been known to the Arabian astronomers. But none of these ancient writers offers any explanation of the cause of the moon's action. Roger Bacon, however, in the thirteenth century, and Kepler in the seventeenth century, state distinctly that the tides are due to the moon's attraction. But they could make no calculation as to the height of the tides, for the *law* of gravitation had not then been discovered.

Galileo seems to have differed from the general opinion on the subject. He thought that the tides were in some way caused by the earth's motion of rotation and revolution. But his theory did not agree with the observed facts. Descartes, in 1644, returned to the lunar theory, but as he did not know the law of gravitation, he could not make much progress in the matter. He tried to connect the tides with his imaginary fluid which carried the planets round the sun, but his theory failed to represent the observation, and had to be abandoned. Newton's discovery when applied to the tides by Laplace, was found to be quite satisfactory, and this formed another proof of the law of gravitation.

Let us now consider some further proofs of this remarkable law. Newton himself seems to have gone no further than to show the cause of the phenomena, and did not enter into any numerical details. These calculations were soon taken up by his successors in the field of mathematical astronomy. Clairaut found for the motion of the moon's perigee only half the value given by observation, and went so far as to suggest that some change was necessary in the law of the inverse square. Buffon, however, believing in the truth of Newton's discovery, suggested that the difference found by Clairaut was due to an error in the calculations. He therefore tried to induce Clairaut to re-examine his work. This, after some hesitation, Clairaut did, and found that when his calculations were carried to a greater degree of accuracy, the difference disappeared, and his results agreed with observation. This was the first great triumph for the law of gravitation.

---

[1] He says, "*Eadem nocte accidit, ut esset luna plena, qui dies maritimas æstus maximos in Oceano efficere consuevit.*"

A second difficulty was soon found in the variation of the velocities of Jupiter and Saturn in their orbits, a variation which had long been a subject of mystery. The deviation is rather considerable, amounting in the course of 2000 years to a difference of 3° 49′ in the longitude of Jupiter, and 9° 15′ in that of Saturn. The question having been carefully investigated by the famous Laplace, he found that the observed deviation was due to the fact that five revolutions of Jupiter were almost exactly equal to two revolutions of Saturn. This fact gives rise to a great reciprocal perturbation between the two planets with a period of about 930 years. This was another great triumph for the law of gravitation.

Another difficulty arose in what is called the secular acceleration of the moon's mean motion, an acceleration which did not seem consistent with the law of gravitation. The acceleration was discovered by Halley. The question was considered by Lagrange in 1774, but he only succeeded in showing that the variation is not due to the influence of the earth's figure on the moon's motion. In fact, he found no explanation for the observed acceleration. Laplace was, however, more successful, and showed, in 1786, that the acceleration was caused by the secular diminution in the eccentricity of the earth's orbit. Although this theory undoubtedly explains the *cause* of the observed acceleration, it does not seem to indicate the *amount* of the acceleration with sufficient accuracy, the theoretical amount being about 6 seconds per century, while the observed quantity is about 8 seconds. It has been suggested that the difference between calculation and observation may possibly be due to a slow change in the length of the terrestrial day, caused by a retardation of the earth's rotation on its axis produced by tidal friction. This slight lengthening of the day would diminish the number of seconds in a month, and thus make the month *apparently* shorter. But the amount of this supposed action of the tides on the earth's rotation is at present very uncertain.

There are some other irregularities in the solar system which the law of gravitation does not explain exactly. Among these may be mentioned the secular movement of the perihelion of Mercury's orbit, which exceeds in amount that indicated by theory. This difference cannot be explained by the action of unknown planets between Mercury and the sun, for if this were the cause, it may be shown that the node of the orbit would also be affected, and observations show that this is not the case.

There are also some small irregularities in the moon's motion which are not well represented by calculation. Professor Newcomb has found one which may perhaps be due to perturbations caused by the planet Jupiter. There are others, however, which have not yet been thoroughly explained, or of which the coefficients in the mathematical formulæ have not yet been accurately determined. In fact, the observation of the moon's place at any time cannot be represented to within less than 5 or 6 seconds. But these are minor points, and, notwithstanding slight differences between theory and observation, we may say that Newton's law of gravitation gives a true explanation of very numerous phenomena. It is one of the greatest examples in the whole range of science of the principle of inductive reasoning confirmed by an appeal to the crucial test of observation.

After Newton's death, his work was continued by several famous mathematicians. In the words of the unfortunate Bailly,[1] "As the empire of Alexander was divided among his successors, so the sceptre of Newton passed into the hands of Clairaut, Euler, and D'Alembert." To these illustrious names may be added those of Lagrange and Laplace.

---

[1] Jean Sylvain Bailly lost his life during the French Revolution. He was guillotined at Paris on November 10, 1793, on the same day that the "Feast of Reason" was held in the Cathedral of Notre Dame.

CHAPTER IX

MICHELL'S ASTRONOMICAL VIEWS

ONE of the boldest and most original thinkers on astronomical subjects was the Rev. John Michell, B.D., F.R.S., who lived in the eighteenth century. He immediately preceded Sir William Herschel, whose fame seems to have eclipsed that of his great predecessor. Michell was born in 1725, and took his degree at Cambridge as fourth wrangler in 1748, when Sir William Herschel was only ten years old. Michell's name is not even mentioned in many biographical works which give a lengthy account of much smaller men, and his name is hardly known to the general reader. This may be partly due to the fact that his speculations were far in advance of his time; but he certainly anticipated many facts and theories which are now known to be true, and some of his theories have been unfairly credited to other astronomers. The discovery of binary or revolving double stars is really due to Michell, although usually ascribed to Sir William Herschel. It was clearly shown by Michell that very close pairs of stars are probably physically connected and revolve round each other, and the fact was afterwards proved by Sir William Herschel from actual measurements. Michell was a Fellow of Queen's College, Cambridge, where he held several professorships between the years 1751 and 1762. He was elected Fellow of the Royal Society in 1760. Later on he became Rector of Thornhill in Yorkshire, and died there on April 21, 1793. His views are very original and suggestive, and he is certainly entitled to rank among the greatest of English philosophers.

In the year 1767 Michell published a very interesting and remarkable paper in the *Philosophical Transactions* of the Royal Society for that year. The title of the paper is, "*An Inquiry into the probable Parallax and Magnitude of the fixed Stars from the Quantity of Light which they afford us, and the particular Circumstance of their Situation.*" In this important paper Michell arrives at some conclusions which were very much in advance of his time. Some of these views are now known to be correct, and a short account of his speculations may prove of interest.

He first states that the distance of the stars is so great that a good determination of their parallax had not been made in his time. In order to arrive at some estimate of their probable distance from the earth, he assumes—and his assumption was a very reasonable one—that, on the average, the stars are equal in size and "natural brightness" to our own sun. By "natural brightness" he evidently means the intrinsic brightness, or luminosity, of their surface per unit of area. He then attempts to compare the brightest fixed stars with the planet Saturn. He assumes that when the earth and Saturn are at their mean distances from the sun, and the rings invisible, the planet is "nearly equal in light to the most luminous fixed stars." If by this expression he means an average star of the first magnitude, the estimate is about correct, for, according to the Harvard photometric measures, Saturn, without his rings, is very slightly brighter than an average star of the first magnitude. It would not, of course, be true for Sirius and the very brightest stars, which are brighter than the first magnitude. Taking into account Saturn's distance from the sun, and his apparent diameter, and assuming that the planet reflects all the light which falls upon it, he finds that the light of the sun is 48,400,000,000 times that of Saturn. Hence the sun should be removed to a distance equal to the square root of this, or about 220,000 times its present distance, in order to reduce its light to that of a star of the first magnitude. This would give a parallax of about one second of arc for stars of this magnitude. This is not far from the truth in the case of α Centauri, the nearest of the stars, but would not be correct for *all* stars of the first magnitude, most of which are certainly at a much greater distance. Making allowance for the want of reflecting power in Saturn, he assumes that it reflects "only a fourth or a sixth" of the light which falls upon it. But this estimate is too small, and assuming an "albedo" of 0·52, as found by Zöllner, the above distance should be increased by the square root of $\frac{1}{0{\cdot}52}$. This would make the distance about 303,000 times, and the parallax about 0·68 second. This is a remarkably close approximation to the parallax of α Centauri (0·75 second).

Michell suggests, however, that both the magnitude and brightness of the stars may differ greatly from those of the sun, but that, on an average, the assumption of equal size and brightness may not "be wide of the truth," "some exceeding and some falling short of it." He adds, "we may perhaps judge in some degree of the native brightness of different stars with respect to one another by their colour, those which afford the whitest light being probably the most luminous." This is another remarkable prediction, which we now know to be true, Sirius and other white stars being much more luminous than the sun in proportion to their mass. In connection with this portion of his researches he anticipates a method of calculation of the brightness of binary stars which is now used to determine their relative brightness from their computed orbits. He says (p. 238, footnote)—

> "If, however, it should hereafter be found that any of the stars have others revolving round them (for no satellite shining by borrowed light could possibly be visible [1]), we should then have the means of discovering the proportion between the light of the sun and the light of the stars, relatively to their respective quantities of matter [that is, their mass]; for in this case the times of the revolutions, and the greatest apparent elongation of those stars that revolved about the others as satellites, being known, the relation between the apparent diameter and the densities of the central stars would be given, whatever their distance from us; and the actual quantity of matter which they contained would be known whenever their distance was known, being greater or less in the proportion of the cube of that distance. Hence supposing them to be of the same density as the sun, the proportion of the brightness of their surfaces, compared with that of the sun, would be known from the comparison of the whole of the light which we receive from them, with that which we

---

* This is quite correct, as I have shown elsewhere. See my "Studies in Astronomy," p. 113.

receive from the sun; but if they should happen to be either of greater or less density than the sun, the whole of their light not being as affected by these suppositions, their surface would indeed be more or less luminous, accordingly as they were, upon this account, less or greater; but the quantity of light, corresponding to the same quantity of matter, would still remain the same.

"The apparent distances at which satellites would revolve about any star would be equal to the semi-annual parallaxes of these stars, seen from planets revolving about the sun, in the same periodical times with themselves, supposing the parallaxes to be such, as they would be, if the stars were of the same size and density with the sun."

Here we have a clear account of the method now used for comparing the relative brightness of binary stars, and the credit of the suggestion seems certainly due to Michell. The above extract also shows that he saw the probability of the existence of binary stars—afterwards *proved* by Sir William Herschel. He again considers the hypothesis further on in the same paper.

He states his opinion that the apparent diameter of the stars must be exceedingly small, and that even in the case of Sirius it must be less than "the hundredth, probably the two-hundredth part of a second," and could not be seen with a telescope magnifying 6000 times. This we now know to be quite correct; the apparent diameter of α Centauri—the nearest of the stars—certainly does not exceed the hundredth of a second. The impossibility of determining the apparent diameters of the stars compels us therefore to estimate their size by their parallax and the quantity of light which they emit compared with that of the sun. This would, however, give only an approximate result, as some of the stars may be more expanded than the sun—that is, of less density, as is probably the case with Sirius; or more condensed, as its satellite may be.

Assuming the parallax of Sirius to be about one second, he proceeds to determine the probable parallax of the fainter stars. He says that the light of Sirius does not exceed that of stars of the sixth magnitude in a greater proportion than 1000 to 1, nor a less proportion than 400 to 1,[1] and he thought that the smaller stars of the second magnitude are about a mean between the two. From this he concludes that stars of the sixth magnitude are at a distance of from 8,000,000 to 12,000,000 times that of the sun, and the distance of small second-magnitude stars would be about 2,000,000 times the same distance. On the hypothesis of equal size and brightness, modern measures would make the parallax of sixth-magnitude stars (compared with Sirius) about the hundredth of a second, or about 20,000,000 times the sun's distance. Compared, however, with α Centauri, their parallax would be about 0·05 second, or only about 4,000,000 times the same distance.

Michell thought that the collection of the stars into groups or constellations is due to "some general law (such, perhaps, as gravity)," and he considers "what it is probable would have been the least apparent distance of any two or more stars, anywhere in the whole heavens, upon the supposition that they had been scattered by mere chance." He shows that for two stars the probability against one star being by chance within 1° of another star is about 13,131 to 1. We must, however, consider the number of stars in the sky of not less brightness than those in question. For the two stars of β Capricorni he finds that the odds are about 80 to 1 against the combination being a chance one. For the Pleiades he finds the odds to be 500,000 to 1 "that no six stars out of the number (1500) scattered at random, in the whole heavens, would be within so small a distance from each other as the Pleiades are." He says that the Pleiades, examined with a telescope, show a large number of smaller stars, and that this increases the odds against their collection by chance to "many millions to one." But we now know that this reasoning is not valid; for although photography has shown over 2000 stars in the group, it has also shown that the surrounding sky is on all sides equally rich in small stars. It therefore seems that most of the fainter stars in the Pleiades do not belong to the cluster, but are probably far behind it in space.

---

[1] Modern photometric measures make Sirius about 1000 times brighter than an average star of the sixth magnitude.

With reference to the "proper motions" of stars, he says, "This apparent change of situation may be owing either to the real motion of the stars themselves, or to that of the sun, or partly to the one and partly to the other" (footnote, p. 252). This is a remarkable prediction, and one we now know to be perfectly correct. He supposes that there may be some faint stars which have a "less real magnitude," and may "belong to the same system with the sun," and for these a parallax might be found. This is another remarkable forecast. Several faint stars are now known which have a larger parallax than many of the brighter stars, and these are probably much smaller than our sun. He seems to think that variable stars and red stars may perhaps be nearer to us than others. But this surmise has not been verified. Variable stars seem to lie at a great distance from our system, and very few red stars have any measurable parallax.

Assuming the number of stars belonging to our system at about 1000, and supposing the sun to be an average-sized member of the group, Michell finds that at the mean distance of the other stars he would "probably rank only with stars of the fourth magnitude," and taking the parallax of Sirius at one second, the parallax of one-half the stars of the group would be about $\frac{4}{60}$ of a second, or about 0·07 second, and the parallax of none of these would much exceed $\frac{2}{3}$ of a second. Supposing the number of stars in the solar group to be only 350, the sun would then rank with stars of the third magnitude, and in this case the parallax of one-half of the stars would be about 0·14 second, and the parallax of none of them would be more than one second. In the case of 1000 stars in the group, he thought that the largest stars would not be more than 1000 times the size of the sun, and if the group contains only 350 stars, the largest stars would perhaps exceed the sun "in the proportion of about 120 to 1."

He then returns to the Pleiades, and attempts to find the probable distance of the cluster. Assuming that the cluster has no great extension in the line of sight, or, in other words, that it is roughly globular in form, and further assuming that the average distance between the six stars visible to the naked eye is equal to the average distance between the stars of the supposed solar cluster, he finds that the probable distance of the Pleiades (assuming their diameter to be about 2°) is "about 57 times as great as the mean distance of the stars of our system from the earth." From this he concludes that η Tauri (Alcyone)—the brightest of the Pleiades—is about 185 times larger than Sirius, and possibly this estimate of its size may not be far from the truth.

With reference to the nebulæ, Michell suggests that many of them may consist of stars not distinguishable by the telescopes in use in his time—another remarkable prediction which has been fully verified by modern observations.

In the *Philosophical Transactions* for the year 1784 there is another paper by Michell with the title, "*On the Means of discovering the Distance, Magnitude, etc., of the fixed Stars, in consequence of the Diminution of the Velocity of their Light, in case such a Diminution should be found to take place in any of them, and such other Data should be procured from Observation as would be farther necessary for that Purpose.*" (*In a letter to Henry Cavendish, Esq., F.R.S. and A.S.*) In this paper he considers the possibility of finding the distance of the stars from "the diminution of the velocity of light" due to the attraction of the stars themselves. This idea was of course based on the "corpuscular theory" of light, which supposed that light was due to small corpuscles shot out by the sun and stars, a theory which was then in vogue. On this theory the velocity of the particles emitted would be gradually reduced by the attraction of the sun or star, in the same way that a body projected upwards from the earth gradually loses its velocity, and after a time is drawn back to the earth again. If, however, the velocity of projection were sufficiently great, the body would not return. On this theory, if a star had a sufficiently enormous mass it might be able eventually to destroy the velocity of the emitted light corpuscles and draw them back to its surface. In this case the star would be invisible, as none of its light could reach us. This was a very ingenious speculation, but the corpuscular theory having been abandoned in favour of the wave theory, Michell's views on this matter are now untenable. He gives some calculations with reference to the size of a body which would be sufficient to draw back the emitted light corpuscles, and finds that its diameter should be at least 497 times the sun's diameter, the densities of the star bodies being the same. This would give an enormous mass, but even with such a mass, we now know that there would be no diminution in the velocity of light.

Michell clearly shows in this paper that he was aware of the probable existence of binary stars, thus anticipating Sir William Herschel. He says, "The very great number of stars that have been discovered to be double, triple, etc., particularly by Mr. HERSCHEL, if we apply the doctrine of chance, as I have heretofore done in my 'Enquiry into the Probable Parallax, etc., of the Fixed Stars,' published in the *Philosophical Transactions* for the year 1767, cannot leave a doubt with any one, who is properly aware of the force of those arguments, that by far the greatest part, if not all of them, are systems of stars so near to each other, as probably to be liable to be affected sensibly by their mutual gravitation; and it is therefore not unlikely that the periods of revolution of some of these about their principals (the smaller ones being, upon this hypothesis, to be considered as satellites to the others) may some time or other be discovered." This remarkable prediction has been abundantly fulfilled. The orbits of over fifty binary stars have now (1906) been accurately computed, and many others are known to be certainly binary.

With reference to the real brightness of the stars, Michell says, "It is not unreasonable to suspect that very possibly some of the fixed stars may have so little natural brightness in proportion to their magnitude, as to admit of their diameters having some sensible apparent size, when they shall come to be more carefully examined, and with larger and better telescopes than have been hitherto in common use." None of the stars have been found to show any real disc, but some small planetary nebulæ are now known which look like faint stars in the telescope at first sight, but show a perceptible disc when examined with high magnifying powers. Michell also suggests that some variable stars, like Mira Ceti, might possibly show a disc with high powers, but this idea has not been verified.

He makes another remarkable prediction with reference to supposed dark bodies in space. He says, "If there should exist in nature any bodies whose density is not less than that of the sun, since their light could not arrive at us; or if there should exist any other bodies of a somewhat smaller size, which are not naturally luminous, of the existence of bodies under either of these circumstances we could have no information from sight; yet if any luminous bodies should happen to revolve about them, we might still perhaps, from the motions of these revolving bodies, infer the existence of the central ones with some degree of probability, as this might afford a clue to some of the apparent irregularities of the revolving bodies, which would not be easily explicable on any other hypothesis." This idea, although based on an erroneous hypothesis, has been fully realized by the discovery of spectroscopic binaries, and the satellites of Sirius and Procyon.

Michell did other scientific work. He invented the well-known torsion balance for weighing the earth. The invention of this instrument is often ascribed to Cavendish, who used it in his famous experiment. But the invention was really due to Michell, and this was admitted by Cavendish himself in a communication to the Royal Society. In a paper read on June 21, 1798, Cavendish says, "Many years ago, the late Rev. JOHN MICHELL, of this Society, contrived a method of determining the density of the earth by rendering sensible the attraction of small quantities of matter; but, as he was engaged in other pursuits, he did not complete the apparatus till a short time before his death, and did not live to make any experiments with it. After his death, the apparatus came to the Rev. FRANCIS JOHN HYDE WOLLASTON, Jacksonian Professor at Cambridge, who, not having conveniences for making experiments with it, was so good as to give it to me."[1]

---

[1] *Phil. Trans.*, 1798, p. 469.

CHAPTER X

SIR WILLIAM HERSCHEL'S ASTRONOMICAL THEORIES AND OBSERVATIONS

"Cœlorum perrupit claustra."[1]

THE famous astronomer, Sir William Herschel, was an excellent observer, and his astronomical theories were bold and suggestive, although always controlled by philosophic caution. In the following pages I propose to consider especially his nebular and sidereal theories. His papers on "the construction of the heavens" and the constitution of the Milky Way, star clusters, and nebulæ, are scattered through the volumes of the *Philosophical Transactions* of the Royal Society for the years 1784 to 1818, and as these volumes are not to be found in every library, an account of Herschel's theories and observations may prove of interest to the general reader.

Before considering these theories, let us first glance at some papers of Herschel's on the distance of the fixed stars, and on the sun's motion in space. In the *Philosophical Transactions* for 1782 (p. 82) there is a paper by Herschel, "On the Parallax of the Fixed Stars." He says that up to his time the best observations made with a view to determine the distance of the stars had only succeeded in giving "a distant approximation" to the truth, but showed that the distance of the nearest star "cannot be less than forty thousand diameters of the whole annual orbit of the earth." The want of a base line sufficiently long for the purpose is the great difficulty in this investigation, for, as Herschel says, "the whole diameter of the annual orbit of the earth is a mere point when compared to the immense distance of the stars." After describing the difficulties connected with the measurement of the star's parallax by the direct method, owing to refraction, nutation, precession, aberration, etc., he describes the method of measuring the parallax by observations of two stars apparently close together, but in which one of them is far behind the other in space. This method, he says, was first suggested by Galileo, who did not, however, suppose the two stars to be very close together (that is, apparently close). The method was also mentioned by other astronomers. To fulfil the necessary conditions for success, he says that the stars forming the optical double—as such doubles are now termed—must be close together, and must "differ as much in magnitude as we can find them." He thought that by this method it would be possible to find a parallax as small as the tenth of a second of arc, and shows that the errors due to refraction, aberration of light, etc., will be imperceptible in such observations. He advocates the use of high powers for the measurement of the companions of double stars, but says that ϵ Boötis will not bear the same power as Castor; stars which are equal, or nearly so, bearing a higher power than those with unequal components. He found that an eyepiece with a single lens was much preferable to one with two lenses.

---

[1] From his epitaph in the church of St. Lawrence at Upton.

Modern practice, however, does not seem to favour this conclusion. High powers, he thinks, "absolutely necessary" in the search for parallax among the stars.

He then gives an account of his search for suitable double stars for the purpose of parallax determination. In this search he depended more on his own actual observations than on the results found by previous observers, and says, "Nature, that great volume, appeared to me to contain the best catalogue upon this occasion." Among the stars he first selected for the purpose were the double star "in the breast of the Virgin," "the first star in Aries," and some near the great nebula in Orion. During this survey of the heavens he collected the materials for his catalogues of double stars which were published in the same volume of the *Philosophical Transactions* (1782). With reference to a few of these objects which had been previously discovered by other observers, he makes the rather quaint remark, "It is a little hard upon young astronomers to be obliged to discover *over again*[1] what has already been discovered."

When the distance between the components of a double star is very small, Herschel estimated the distance in "measures of their own apparent diameters." This method was used when the distance did "not much exceed two diameters of the largest." He gives examples of double stars of various degrees of difficulty. For telescopes of small power, magnifying from 40 to 100 times, he recommends the following as tests for the quality of the instrument: ζ Ursæ Majoris, γ Delphini, γ

---

[1] The italics are Herschel's.

Arietis, π Bootis, γ Virginis, ι Cassiopeiæ, and μ Cygni. He then gives a mathematical investigation of the method of finding the parallax from observations of double stars, but this is too technical to reproduce here.

In the *Philosophical Transactions* for 1783, there is a paper by Herschel, "On the Proper Motion of the Sun and Solar System; with an Account of several Changes that have happened among the Fixed Stars since the time of Mr. Flamstead."[1] He refers to the proper motion of the ~~stars Arcturus, Sirius,~~ Aldebaran, Procyon, Castor, Rigel, and ~~Altair ; and~~ says that on account of the great distance of some ~~stars~~ from the earth, we cannot expect that ~~their proper~~ motions would ~~become perceptible~~ for ages, and he makes ~~the interesting~~ remark, "This consideration alone would lead us strongly to suspect that there is not, in strictness of speaking, one *fixed* star in the heavens." Modern observations tend to confirm the accuracy of Herschel's prediction.

He then considers some apparent changes of brightness which have occurred in certain stars since Flamsteed's time. Among these he mentions 80 and 81 Herculis, 56 Cancri, 19 Persei, 108 Piscium, 73 and 74 Cancri, 8 Hydræ, 26 Cancri, 62 Orionis, 71 Hercules, 19 and 34 Comæ Berenices, which he seems to think had disappeared. But errors of observation by Flamsteed may possibly account for Herschel's failure to find these stars.

Among stars which have apparently changed in brightness, he mentions α Draconis, β Ceti, ζ Serpentis, η Cygni, η Bootis, ι Delphini, β Trianguli, γ Aquilæ, σ Sagittarii, δ Canis Majoris, η Serpentis, κ Serpentarii, β Equulei, δ Delphini, ϵ Boötis, δ Sagittæ, α and δ Ursæ Majoris, γ and β Lyræ, and ξ Leonis. Of these, the only star which has since been *proved* to be really variable is β Lyræ.

---

[1] This is Herschel's spelling of the first Astronomer Royal's name; but it is now generally spelled Flamsteed.

Among stars which he thinks have "newly come to be visible," he mentions several stars between the fourth and sixth magnitudes, not seen or overlooked by Flamsteed. He thinks, however, that it is not easy to prove that a star has recently become visible, and he lays "no particular stress on the new appearance of the above stars," but recommends further observation of these objects.

Herschel then proceeds to consider the question of the sun's motion in space. He says, (1) "The greatest or total systematic parallax"—as he terms the apparent change of place in the stars due to the sun's motion—"will take place along a line at right angles to the direction of the solar motion." This is evident. (2) The "systematical parallax" of other stars, not in this line, will be the maximum parallax multiplied by the sine of the angle between the place of the star and the direction of the solar motion. This will also be obvious to any reader who understands the first principles of trigonometry. (3) "The parallax of the stars at different distances will be inversely as those distances." That is, the nearer the star, the greater its apparent displacement or parallax; and the farther the star is from the earth, the smaller its parallax will be. This is also sufficiently clear. (4) "Every star at rest, to a system in motion, will appear to move in a direction contrary to that in which the system is moving." This is also evident. The apparent motion of distant objects seen from a railway train in motion will show the truth of this assumption. Assuming these principles, Herschel selected a number of stars, and from their "proper motions," or apparent motion on the face of the sky, he deduced the direction of the sun's motion in space. He first chose seven stars, namely, Sirius, Castor, Procyon, Pollux, Regulus, Arcturus, and Altair, and he found that the proper motions of these stars indicated a solar motion towards the constellation Hercules. To test the accuracy of this result, he took twelve stars, namely, Arcturus, Sirius, β Cygni, Procyon, ε Cygni, γ Arietis, γ Geminorum, Aldebaran, β Geminorum, γ Piscium, α Aquilæ, and α Geminorum. Adding Regulus, and Castor being double, made fourteen stars. From the proper motions of these he obtained 27 motions in right ascension and declination. Assuming a point near λ Herculis for the solar "apex"—as Herschel termed the point towards which the sun is moving—he found that this point satisfied 22 of these motions and he thought that the five exceptions were due to the real motions of the stars themselves. He found that the apparent motion of Pollux "agrees wonderfully with observations," but Castor not so well, and he thought it probable that "its distance may be double that of Pollux." But modern measures have not confirmed this supposition.

With reference to the annual amount of the solar motion, Herschel thought that "the diameter of the earth's orbit, at the distance of Sirius or Arcturus, would not nearly subtend an angle of one second; but the apparent motion of Arcturus, if owing to the translation of the solar system, amounts to no less than "2·7 seconds a year," and he concludes "that the solar motion can certainly not be less than that which the earth has in her annual orbit." Modern measures, however, make the motion about eleven or twelve miles a second. From an examination of the proper motion of a number of stars observed by Mayer in 1756, compared with Roemer's observations in 1706, Herschel found a confirmation of his previous result. He mentions that Mayer had previously (in 1760) suggested a solar motion as possible, and that Lalande had made a similar suggestion in 1776.[1]

The first paper in which Herschel definitely considers the subject of "the construction of the heavens" appeared in the volume of the *Philosophical Transactions* for the year 1784 (p. 437). He begins by stating that the instrument he used in his observations was a reflecting telescope of the Newtonian form, the mirror having a clear aperture of 18·7 inches, with a focal length of twenty feet, which was in those times a very large telescope indeed. He used this instrument in an investigation of what he terms "the *interior construction* of the heavens, and its various *nebulous* and *sidereal strata* (to borrow a term from the natural historian)." On turning this large telescope on the Milky Way, he found that the nebulous light visible to the naked eye was wholly resolved into small stars. This his earlier telescope failed to do completely, although the Galaxy had been partially resolved into stars by earlier observers. The portion of the Milky Way first examined by Herschel was that near the hand and "club" of Orion, that is, near the stars ν and ξ Orionis, and north of the bright star Betelgeuse.

---

[1] This was also suggested by Michell in 1767. See chapter on Michell's views.

He found the small stars in this region very numerous and of various degrees of brightness. To avoid being misled by the "dazzling brightness" of such a multitude of stars, he attempted to ascertain their real number by actually counting those visible in numerous "fields" of his telescope, and taking an average of these various counts. In six fields taken at random he counted 110, 60, 70, 90, 70, and 74 stars, which gives an average of 79. Selecting "the most vacant place" he could find in this region, he counted 63 stars in the field of view.

Now, allowing fifteen minutes of arc for the diameter of the field of view, he concluded that a belt or zone of 15° long and 2° wide "could not well contain less than fifty thousand stars," bright enough to be distinctly counted. In addition to this large number, he "suspected at least twice as many more," which, for want of light in the telescope, he "could only see by faint glittering and interrupted glimpses." The larger estimate would give 5000 stars to the square degree, and, if the whole heavens were equally rich in stars—which, of course, it is not—would give, I find, a total of 206 millions of stars.

With the large telescope Herschel found that many of Messier's nebulæ described by him as nebulæ containing no stars, "appeared to be nothing but stars, or at least to contain stars, and to show every other indication of consisting of them entirely." Even those described by Messier as clusters of stars containing nebulosity were found to be completely resolved. Messier's failure to resolve these "nebulæ' was, of course, due to want of power in the telescope he used. Herschel describes No. 53 of Messier's catalogue as "one of the most beautiful objects

I remember to have seen in the heavens. The cluster appears under the form of a solid ball, consisting of small stars, quite compressed into a blaze of light, with a great number of loose ones surrounding it, and distinctly visible in the general mass." This fine cluster lies a little north-west of the star α Comæ Berenices.

At this period of his investigations, Herschel thought that the nebulæ and clusters of stars might "surround the whole apparent sphere of the heavens, not unlike the Milky Way, which undoubtedly is nothing but a stratum of fixed stars." He found one of the nebulous regions, or "strata," as he calls them, so rich in nebulæ that in a period of 36 minutes he detected 31 nebulæ, "all distinctly visible on a fine bue sky." He also noticed double and treble nebulæ, but probably some of these were various forms of those now known as spiral nebulæ.

Herschel thought it very probable that our sun is placed in the "great stratum" forming the Milky Way, "though perhaps not in the very centre of its thickness." Recent researches seem to confirm this opinion, namely, that the sun is nearly, but not exactly, in the centre of the Galactic plane. Starting from this assumption, Herschel then proceeds to explain his famous theory of the Milky Way commonly known as the "disc theory." This theory, usually ascribed to Sir William Herschel, was originally advanced in 1750 by Thomas Wright, of Durham, that is, 34 years before the publication of Herschel's paper in the *Philosophical Transactions.* The theory is usually spoken of as the "disc" theory, but in Herschel's original drawing the sidereal system is represented as a rectangular slab of considerable length and width in proportion to its thickness. This seems to have been his first conception, but it was probably afterwards modified, as in a subsequent drawing he represents the Milky Way in the form of a section of an irregular circular disc. He supposed that the edge of this hypothetical layer was split at one end, in order to account for the division, or apparent division, in the Milky Way between Cygnus and Scorpio. He then considers the hypothesis of a ring shape for the Galaxy, but thinks that it would be "not a little extraordinary that the sun, being a fixed star like those which compose this imagined ring, should just be in the centre of such a multitude of celestial bodies, without any apparent reason for this singular distinction; whereas, on our supposition, every star in this stratum, not very near the termination of its length or height, will be so placed as also to have its own Galaxy, with only such variations in the form and lustre of it as may arise from the particular situation of each star."

He then proceeds to consider the question, how we are to determine the sun's plane in this supposed stratum of stars, and describes his method of "*Gaging the Heavens*, or the *Star Gage*." This method consisted in counting the number of stars visible in the field of his telescope, taking the mean of ten fields "very near each other." He says these "gages," of course, vary with the size of the telescope used in the inquiry, and on this point he quotes a remark of the famous French astronomer, De la Lande, of which the following is a translation :—

"We see with telescopes stars in all parts of the sky, a little closer in the Milky Way or the nebulæ.

We cannot doubt that a part of the light and whiteness of the Milky Way proceeds from the light of small stars, which are found there by millions; however, with the largest telescopes we do not sufficiently distinguish them, and they are not sufficiently near enough to attribute to this the whiteness of the Milky Way, so evident to the naked eye. We cannot then affirm that the stars are the sole cause of the whiteness, although we know no other satisfactory way of explaining it."

Possibly the nebulosity visible in the Milky Way in modern photographs may help to explain this "whiteness."

Herschel then explains how the sun's position in the supposed stratum of stars may be ascertained by the number of stars in each "gage," which should indicate the length of the "ray," or thickness of the stratum, in the given direction. He finds that the direction of the solar motion in space is nearly in the direction of one of the "nodes" of the Milky Way. By the term "node" he means the "union of two strata," like those in Cepheus and Cassiopeia, and in Scorpio and Sagittarius. He here refers to his observations of the nebulæ, and remarks that "the spaces preceding them were generally quite deprived of their stars, so as often to afford many fields without a single star in it; that the nebulæ generally appeared some time after among stars of a certain considerable size, and but seldom among small stars; that when I came to one nebula, I generally found several more in the neighbourhood; that afterwards a considerable time passed before I came to another parcel; and these events being thus repeated in different altitudes of my instrument, and some of them at a considerable distance from each other, it occurred to me that the intermediate spaces between the sweeps might also contain nebulæ; and finding this to hold good more than once, I ventured to give notice to my assistant at the clock to prepare, since I expected in a few minutes to come at a stratum of the nebulæ, finding myself already (as I then figuratively expressed it) on nebulous ground. In this I succeeded immediately."[1] This is an interesting observation, and is confirmed by modern observations.

With reference to the direction of some of the "capital strata," as he calls them, "or their branches," he mentions the well-known nebula of Cancer, which runs from ϵ Cancri[2] towards the south over the 67 nebula of the *Connoissance des Temps* [Messier 67]. He thought that it probably belonged to "a certain stratum in which I suppose it to be so placed as to be nearest to us." He describes it as "a very beautiful and pretty much compressed cluster of stars, easily to be seen by any good telescope, and in which I have observed above 200 stars at once in the field of view of my great reflector with a power of 157." This description seems to refer to Messier 67.

Another stratum which he thought is probably "nearer to the solar system than any of the rest," is that containing Coma Berenices, this open cluster perhaps forming one of the clusters in the stratum which he thought "runs on a very considerable way," perhaps even round the heavens, "through the Great Bear onwards to Cassiopeia; then through the girdle of Andromeda and the Northern Fish, proceeding towards Cetus; while towards the south it passes through the Virgin, probably on to the tail of Hydra and the head of Centaurus." He thought this stratum lies nearly at right angles "to the great sidereal stratum in which the sun is placed."

---

[1] These are Herschel's words. They are often quoted incorrectly in books on astronomy.

[2] This is Messier 44, the so-called Præsepe.

Having "gaged" the Milky Way in various directions, he found that the number of stars composing it "constantly increase and decrease in proportion to its apparent brightness to the naked eye." This important observation shows that the varying brightness of the Milky Way is really due to its varying richness in stars, and not to varying distance from the earth as some writers have incorrectly supposed. Modern photographs confirm Herschel's conclusion.

Supposing that the stars are of various sizes and almost equally distributed in space, he found the following results with reference to the nebulæ.

1. When a star is considerably larger than its neighbours, it will attract them round it, and thus form a cluster of almost a globular form. This idea was evidently suggested by the appearance of the globular clusters, but modern researches seem to suggest that the globular clusters were more probably formed by the condensation of nebulous matter.

2. In the case where a number of stars, although not much larger than the others, happen to be nearer each other, are drawn together by the force of attraction, thus forming an irregular cluster. Here, again, it now seems more probable that irregular clusters were originally formed by the

condensation of gaseous masses. The Pleiades, with their surrounding nebulosity, is an example.

3. A combination of the preceding causes may produce another form of cluster, in which large and small stars "are situated in long extended, regular, or crooked rows, hooks, or branches."

4. More extensive combinations may produce clusters not very far separated from each other. This hypothesis would account for the observed occurrence of clusters in the same region of the heavens.

5. As the result of these supposed clusterings of stars, "cavities or vacancies" would be formed. This would explain the occurrence of dark spaces or "holes" which are found in various parts of the Milky Way and elsewhere.

Herschel then considers how the stars in clusters are "preserved from rushing on their centres of attraction." He suggests "projectile forces," meaning, of course, motions of the component stars round their common centre of gravity. He says "these clusters may be the *Laboratories* of the universe, if I may so express myself, wherein the vast salutary remedies for the decay of the whole are prepared."

He then proceeds to consider the optical appearance of the heavens as viewed from our standpoint on the earth, and considers that "the stars of the first magnitude, as being in all probability the nearest, will furnish us with a step to begin our scale." This was a very natural supposition, but modern measures of distance do not support the view that the brightest stars are, as a rule, the nearest. They suggest rather that the difference in relative brightness among the stars is due more to difference in absolute size, and also to difference in luminosity of their surface. Following, however, Herschel's hypothesis, he supposes that, taking the distance of Sirius or Arcturus as unity, stars of the second magnitude are at double the distance, those of the third at treble, and so on. He assumes that a star of the seventh magnitude is seven times as far as one of the first.[1] On this supposition an eye placed at the centre of a globular cluster would not see the whole of it, as the distance of the outer stars of the cluster would probably exceed six times the distance of Sirius from the earth. Outside clusters might possibly be seen as small faint nebulæ. He then proceeds to show that his views are consistent with his "gages." He gives a table of these gages taken in various parts of the heavens. This list proceeds regularly in right ascension all round the sky, but varies in declination. The number of stars observed in these "gages" varies enormously, the averages for ten fields ranging from 2·2 to 3·4 stars near the pole of the Milky Way up to 384 near β Cygni, and 588 in Sagitta. The high results were, of course, in the Milky Way.

To determine the length of the visual ray in the method of star-gazing on the hypothesis of stars "equally scattered," Herschel imagined a cone cut into frustra by equidistant planes perpendicular to its axis. Then if we suppose one star placed at the vertex of the cone and another on the axis at the first intersection, "six other stars may be set around it so as to be equally distant from one another and from the central star." The sums of the numbers of stars in the several sections will then be, 1, 7, 19, 37, 61, 91, etc. The sum of any number n of this series will be n^3. From this he finds that the length of the visual ray may be represented by $n-1$.

---

[1] Herschel's values of distances do not agree with modern measures. With a light ratio of 2·512, a star of the seventh magnitude would be nearly sixteen times the distance of one of the first.

According to Herschel's first view of the construction of the visible universe, "*we inhabit a planet of a star belonging to a compound nebula of the third form.*" This is the heading of a section of his paper in the *Philosophical Transactions* for 1785 (p. 244). He says "the stupendous sidereal system we inhabit, this extensive stratum and its secondary branches, consisting of many millions of stars, is, in all probability, a *detached nebula.*" He then proceeds to find the length of his "sounding line." The "gages" showed a maximum of 588 stars in the "most crowded" parts of the Milky Way. This richness continued, he says, for "many minutes," so that in a quarter of an hour's time there passed no less than 116,000 stars through the field of view of his telescope. From this he finds that the length of the sounding line was not less than 497 times the distance of Sirius from the earth. As modern measures make the distance of Sirius about 8·8 years' journey for light, this result would give for his farthest stars about 4374 "light years," a high but perhaps not improbable value.

To assume an equal distribution of stars in space is, he admits, inaccurate, as most probably no such arrangement exists in reality; but taking all the stars as a whole, "there will be a mean distance which may be assumed as the general one." No unusual collections or clusters of stars were included in the "gages," and he found that the difference between a crowded region and a cluster could be easily perceived by the arrangement of the stars. In a cluster they are generally nearly of the same size, with a certain uniformity of distance between them, and they are also condensed towards a centre. On the other hand, in the rich regions of the Milky Way we find a mixture of stars of all degrees of brightness, and scattered without any special order.

Where the "gages" run below 5, Herschel thought that the stratum cannot exceed 100 times the distance of Sirius, and he says "the same telescope which could show 588 stars in a field of view of 15 minutes must certainly have presented me also with the stars in these situations as well as the former, had they been there." This is an interesting and valuable remark of Herschel's, and shows that he fully realized the fact that the number of existing stars is really small in the directions where the gages showed a small number. This fact shows "that there must be at least a vacancy amounting to the length of a visual ray not short of 400 times the distance of Sirius; and this is amply sufficient to make our nebula a detached one," and he adds, "it is true that it would not be consistent confidently to affirm that we are on an island unless we had actually found ourselves everywhere bounded by the ocean, and therefore I shall go no further than the gages will authorize." Photographs now show strong evidence that our sidereal universe *is* practically "an island" in space. Herschel thought that a larger telescope than the one he used in these researches would probably reveal a much larger number of stars. Thus "a telescope with a threefold power," he thought, would show over 16,000 stars instead of the 588 counted by him. Although modern photographs taken with telescopes larger than Herschel's show an enormous number of stars in the Milky Way, still Herschel's expectations have not been realized. Even photographs in rich regions of the Galaxy show nothing like 16,000 stars in a circle of fifteen minutes of arc in diameter, and many of the stars visible on these photographs are not visible to the eye with the telescope with which they were photographed.

With reference to the probable extent of the Milky Way, Herschel says that his telescope had "the power of showing the united lustre of the accumulated stars that compose a milky nebulosity at a distance far exceeding the former limits; so that from these considerations it appears again highly probable that my present telescope, not showing such a nebulosity in the Milky Way, goes already far beyond its extent: and consequently, much more would an instrument such as I have mentioned, remove all doubt on the subject, both by showing the stars in the continuation of the stratum, and by exposing a very strong milky nebulosity beyond them, that could no longer be mistaken for the dark ground of the heavens."

He then gives a table showing the length of the supposed "visual ray," corresponding to the number of stars visible in the field of view. Thus for 1 star, the length of the ray would be 58 times the distance of Sirius; for 10 stars, 127; for 20, 160; for 30, 184; for 40, 202; for 50, 218; for 100, 275; for 200, 347; for 300, 530; for 500, 471; for 1000, 593; and for 100,000 stars, 2758. Taking the visual ray corresponding to the different "gages" obtained by observation, and plotting these according to right ascensions and north polar distance, he formed a section of our sidereal system (according to his disc theory) of which he gives a drawing.[1] He assumes the north pole of the Milky Way to lie in RA 186°, and north polar distance 58° (Decl. + 32°). This is a little north of the position now usually adopted for the northern Galactic pole. From the figure thus obtained he concludes that "our nebula, as we observed before, is of the third form—that is, *a very extensive branching compound congeries of many millions of stars;* which most probably owes its origin to many remarkably large as well as pretty closely scattered small stars, that may have drawn together the rest."

With reference to the origin of the "nebulous strata"—as he calls them—he says, "the nebula we inhabit might be said to be one that has fewer marks of profound antiquity upon it than the rest." This idea was based on the hypothesis that the "strata" were formed by a gradual approach of the stars, and as our stratum is apparently not so condensed as the clusters are, *it* is probably younger; but such a conclusion is hardly tenable now, as there is reason to believe that our sidereal system includes within its boundaries all known stars, clusters, and nebulæ.

Herschel "surmised" that a nebulous stratum, consisting chiefly of nebulæ of the first and second form, probably owes its origin to the decay of a great nebula of the third form. In the same way he considered it possible that our sidereal system might, in the lapse of ages, become divided up into a stratum of two or three hundred nebulæ, and he thought that he could detect the beginning of the gathering of these clusters, such as the nebulous stratum in Coma Berenices and elsewhere.

---

[1] *Phil. Trans.* for 1785, facing p. 266.

According to Herschel's views of the construction of the heavens, some portions seem to have suffered more from the "ravages of time" than others. To illustrate this idea he refers to a spot "in the body of the Scorpion," where he found "an opening or "hole," probably due to this cause. This hole lies a little north of the star 19 Scorpii. Approaching the Milky Way the gages ran up from 9·7 to 17·1 stars, "when all of a sudden they fell down to nothing, a very few pretty large stars excepted, which made these show 0·5, 0·7, 1·1, 1·4, 1·8; after which they again rose to 4·7, 13·5, 20·3, and soon after to 41·1." This "hole" is about 4° broad. Herschel remarks that the rich globular cluster Messier 80 lies just on the western border of this hole, and he suggests that the stars composing the cluster might have been "collected from that place," thus leaving a vacancy. He found the same result in the case of Messier 4, which is also on the western border of another "hole," with a smaller cluster north-east of it. Messier 4 lies closely west of the bright star Antares (α Scorpii), and not far from the "hole" near Messier 80, referred to above.

Herschel then gives observations of what he calls "compound nebulæ or milky ways." He thought that some of these "cannot well be less, but are probably much larger than our own system." But this hypothesis is not now considered tenable by astronomers. Herschel's views are, however, very interesting, as all his speculations were. His reasons for thinking some of the nebulæ to be external galaxies were as follows. Some of the "round nebulæ" consist of stars which, although very small, he could see distinctly with his telescope, and he estimated these to lie at a distance of 600 times the distance of Sirius. This estimate was based on the supposition that the component stars of these clusters are closer together than the other stars in our system. On the supposition of an equal distribution of stars, he finds that the distance would be 6000 of the same units. Other smaller nebulæ in the neighbourhood of these he estimated to lie much farther from the earth, and he concluded in the case of a nebula "whose light is perfectly milky," that it "cannot be well supposed to be at less than six or eight thousand times the distance of Sirius." Among these supposed external galaxies he mentions "a milky ray" of more than a degree in length, which lies near the star Flamsteed 52 Cygni. A second "faint milky ray," about 15 minutes long by 8 or 10 minutes broad, is found a little south-east of the star ε Cygni. A third is "a branching nebulosity about a degree and a half long by 48 minutes wide," a little north-west of ζ Cygni. A fourth is another "faint, extended milky ray of about 17 minutes in length and 12 minutes in breadth," with another small nebula near it. This object is a little north-west of α Trianguli. A fifth is "a streak of light about 27 minutes long, and in the brightest part 3 or 4 minutes broad." It lies a little south of β Ceti. A sixth is "an extensive milky nebulosity" divided into two parts. Near this is "a cluster," which Herschel thought identical with Messier 8; but Messier 8 is shown by the spectroscope to be gaseous according to Secchi. A seventh is Messier 17, now known as the "Omega nebula.'

Herschel describes it as "a wonderful extensive nebulosity of the milky kind." Sir William Huggins finds a gaseous spectrum, so the idea of an external universe must in this case at least be abandoned. To this list Herschel adds the great nebula in Orion and the great nebula in Andromeda. The Orion nebula is now known to consist of glowing gas, and it is certainly not an external galaxy. Herschel thought that the great nebula in Andromeda "is undoubtedly the nearest of all the great nebulæ." He found that "the brightest part of it approaches to the resolvable nebulosity, and begins to show a faint red colour; which, from many observations on the colour and magnitude of nebulæ, I believe to be an indication that its distance in this coloured part does not exceed 2000 times the distance of Sirius." This estimate does not, however, denote a comparatively near object. It would represent a journey for light of over 17,000 years. He refers to the nebula near it discovered by his sister, Miss Caroline Herschel, and says "it is not Messier 32, which lies about two-thirds of a degree north, preceding it in a line parallel to β and ν Andromedæ." All modern telescopes have failed to resolve the great nebula into stars, but the spectroscope shows a continuous spectrum with some dark lines, which indicates that it is not gaseous. It is probably partially condensed from the gaseous state, and it may consist of small bodies too small to be visible in our largest telescopes. Photographs show it to be spiral. In all probability it belongs to our sidereal system, and is not an external galaxy.

Herschel refers to Messier 57, the so-called ring nebula in Lyra, and he seemed to think that it was resolvable into stars, but Huggins finds a gaseous spectrum.[1]

He then refers to the so-called "planetary nebulæ," which he thought were possibly external galaxies. One of these lies a little west of the star ν Aquarii. He found its diameter to be 10 or 15 seconds; but Secchi made it 25 seconds by 17 seconds. Herschel found its light of a uniform brightness, and "probably of a starry nature," but Huggins finds it to be a mass of glowing gas. This is one of the finest objects of its class. Another planetary nebula observed by Herschel lies a little south-west of Flamsteed 13 Andromedæ, and he describes it as "a well-defined planetary disc of about 12 seconds diameter, a little elliptical. A third object of this class lies a little north, following 44 Ophiuchi; "round, tolerably well defined and pretty bright; its diameter about 30 seconds." A fourth is a little north, following η Sagittæ; "perfectly round; pretty bright, and pretty well defined; about ¾ minute in diameter." A fifth lies a little north, following 21 Vulpeculæ; "exactly round; of an equal light throughout, but pretty faint, and about 1 minute in diameter." A sixth is south preceding 39 Cygni; "perfectly round, and of an equal light, but pretty faint; its diameter is near 1 minute; and the edges are pretty well defined." Considering the telescopic appearance of these planetary nebulæ, Herschel thought that they could hardly be true nebulæ, owing to their uniform and vivid light, and their discs, so small and well defined. On the other hand, he thought they could not be "of a planetary nature." It would also be difficult, he thought, to consider them as "single stars with large diameter," as we could not then account for their comparative faintness. He also rejects the idea that they might be comets near their aphelion, as their size and brightness is against such an hypothesis. From these considerations he is forced to conclude that they must be nebulæ, with the stars "compressed and accumulated in the highest degree"; but as the spectroscope shows them to be gaseous, Herschel's hypothesis is now untenable. Herschel seems to have been much impressed with the appearance of these planetary nebulæ. He says, "If it were not perhaps too hazardous to pursue a former surmise of a renewal in what I figuratively called the laboratories of the universe, the stars forming these extraordinary nebulæ, by some decay or waste of nature, being no longer fit for their former purposes, and having their projectile forces, if any such they had, retarded in each other's atmospheres, may rush at last together, and either in succession, or by one general tremendous shock, unite into a new body. Perhaps the extraordinary and sudden blaze of a new star in Cassiopeia's chair of 1572 might possibly be of such a nature." This is an interesting speculation of Sir William Herschel's, and a remarkable forecast of the probable cause of temporary or new stars, most of those which have appeared in modern years having changed into planetary nebulæ.

---

[1] For further details of this nebula, see chapter on the ring nebula in Lyra in my "Studies in Astronomy."

In the introduction to "A Catalogue of a Second Thousand of New Nebulæ and Clusters of Stars" (*Phil. Trans.* 1788) Herschel speaks of the nebulæ "as being no less than whole sidereal systems;" but such an hypothesis is no longer tenable. He says that "bodies shining only with borrowed light can never be seen at any great distance," and that consequently "every star must likewise be a sun shining by its own native brightness." This is an example of the soundness of Herschel's views in matters of fact like this. Some astronomers have since his time suggested that the faint companions to bright stars, like the satellite of Sirius, might shine by reflected light from the brighter star, but I have shown elsewhere that this is utterly impossible.[1] Herschel thought that all stars had probably "a system of planets, satellites, and comets" revolving round them; and this hypothesis seems a rational one, at least in the case of *single* stars. Binary stars and spectroscopic doubles may possibly form an exception.

With reference to clusters of stars, Herschel shows the great probability there is of the component stars being contained in a comparatively limited space. He quotes Michell's conclusion that the odds are 500,000 to 1 against the six brightest stars of the Pleiades being apparently so close together by merely a chance coincidence, and he argues that the fact of the stars being crowded together in a globular cluster shows that they are "nearly of an equal magnitude," with, however, a certain small variety in size, "in some such proportion as one full-grown plant of a certain species may exceed another full-grown plant of the same species." He also shows that those which are apparently globular in form are really so, the odds against any other form being enormous. These views are undoubtedly sound. He then proves that the globular clusters are in reality more condensed towards the centre, as they seem to be. For if the component stars were equally scattered through the sphere, it would not have a bright nucleus in the centre. He concludes that this spherical figure has been "formed by the action of central powers." The figure of the earth and planets he considers as examples of this "central power," or central force, as it is now termed; and that the form of the globular clusters cannot be due to "any random scattering of stars." The condensation towards the centre proves the action of this "central power"—probably "the known central force of gravity." Even in those clusters which are not exactly globular in form, he thought we have evidence of "a tendence towards sphericity by the swell of the dimensions the nearer we draw towards the most luminous place, denoting as it were a course, or tide of stars setting towards a centre." As Tennyson says (in "The Princess")—

---

[1] See my "Studies in Astronomy," pp. 113-116.

> "This world was once a fluid haze of light
> Till towards the centre set the starry tides,
> And eddied into suns, that, wheeling, cast
> The planets."

In all the nebulæ and clusters observed by Herschel—about 2300 in number—he found this tendency to condensation and increased brightness near the centre, which, he thought, fully established the truth of the hypothesis. There is, however, considerable variety in this appearance of condensation in the middle. This, he thought, might be due partly to the difficulty of seeing distinctly those which lie at great distances from the earth. He thought that the action of this central force "must produce effects proportional to the time of its action," and that consequently the globular clusters are probably older than those of an irregular form. We might thus judge of the relative ages of clusters and nebulæ. On this hypothesis he thought we might conclude that a cluster or nebulæ "which is very gradually more compressed or bright towards the middle may be in the perfection of its growth," while the planetary nebulæ "may be looked upon as very aged." But this view does not now seem so probable as it did to Herschel. A planetary nebulæ formed by a temporary star, far from being aged, is comparatively a thing of yesterday. At the end of this paper Herschel makes his famous remark about the nebulæ and clusters, "For, to continue the simile I have borrowed from the vegetable kingdom, is it not almost the same thing, whether we live successively to witness the germination, blooming, foliage, fecundity, fading, withering, and corruption of a plant, or whether a vast number of specimens, selected from every stage through which the plant passes in the course of its existence, be brought at once to our view?" This is doubtless true, but to decide the question as to which are the oldest and which the youngest nebulæ seems to require more evidence than we possess at present.

In the *Philosophical Transactions* for 1791 there is a paper by Herschel on "Nebulous Stars, properly so called." This is a very interesting paper, as it contains the first evidence of Herschel's change of opinion with reference to the nebula. His first observation of "nebulous stars" was that of "*a star of about the eighth magnitude surrounded with a faintly luminous atmosphere of a considerable extent.*" (The italics are Herschel's.) This greatly surprised him, and seems to have led to his change of views with reference to the real nature of those nebulæ which could not be resolved into stars with his large telescope. He says, "A glance like that of the naturalist, who casts his eye from the perfect animal to the perfect vegetable, is wanting to remove the veil from the mind of the astronomer. The object I have mentioned above, is the phænomenon that was wanting for this purpose. View, for instance, the 19th cluster of my 6th class, and afterwards cast your eye on this cloudy star, and the result will be no less decisive than that of the naturalist we have alluded to. Our judgment, I may venture to say, will be, that *the nebulosity about the star is not of a starry nature*." (The italics are Herschel's.) Here is the first anticipation we have of the revelations of the spectroscope, which shows that many of the nebula consist of nothing but glowing gas. He then refers to "a telescopic milky way" in Orion, apparently connected with the great nebula in the "sword." This is probably identical with the vast nebula recently disclosed by photography in that region. Herschel thought that the four stars known as "the trapezium" (Herschel uses this term), and others, are "intirely unconnected with the nebulosity which involves them in appearance;" but it now appears much more probable that the stars of the trapezium are really connected with the nebulous matter surrounding them.

Herschel speaks of this nebulosity as "luminous matter in a state of modification very different from the construction of a sun or star." He had evidently in his "mind's eye" the probable existence of gaseous masses in space, but says "about things that appear now we ought not to form opinions too hastily." He then gives descriptions of a number of remarkable nebulous stars observed by him. Among these may be mentioned the following: "November 13, 1790. A most singular phenomenon. A star of about the 8th magnitude, with a faint luminous atmosphere, of a circular form, and about 3 minutes in diameter. The star is perfectly in the centre, and the atmosphere is so delicate, faint, and equal throughout, that there can be no surmise of its consisting of stars, nor can there be a doubt of the evident connection between the atmosphere and the star. Another star, not much less in brightness and in the same field with the above, was perfectly free from any such appearance," and he adds, "This last object is so decisive in every particular, that we need not hesitate to admit it as a pattern." This curious object lies about 2° north of ψ Tauri, and nearly in a line with o and ζ Persei (north of the Pleiades). Herschel argues that if this nebulosity consisted of stars, the central point must be of enormous size. On the other hand, if the central star be of an ordinary size, the stars composing the nebulosity must be excessively small and compressed. He therefore concludes that we "either have a central body which is not a star, or have a star which is involved in a shining fluid, of a nature totally unknown to us." This happy idea has long since been fully confirmed by the spectroscope. Nebulous stars are certainly ordinary stars surrounded by glowing gaseous envelopes, and probably in an early stage of their life history. Herschel says, "But what a field of novelty is here opened to our conceptions! A shining fluid of a brightness sufficient to reach from the remote regions of a star of the 8th, 9th, 10th, 11th, and 12th magnitude, and of an extent so considerable as to take up 3, 4, 5, or 6 minutes in diameter. Can we compare it to the coruscations of the electrical fluid in the aurora borealis? Or to the more magnificent cone of the zodiacal light as we see it in the spring and autumn? The latter, notwithstanding I have observed it to reach at least 90° from the sun, is yet of so little extent and brightness as probably not to be perceived even by the inhabitants of Saturn or the Georgian planet,[1] and must be utterly invisible at the remoteness of the nearest fixed star." Herschel thought that this nebulosity might possibly exist without any apparent connection with stars, and he again refers to the nebulous region in Orion, which he speaks of as "a luminous matter accounting much better for it than clustering stars at a distance." That this opinion was sound is shown by the fact that the great nebula in Orion has resisted all the efforts of the largest telescopes to resolve it into stars, and the spectroscope shows that it is nothing but glowing gas. With reference to the distance of the nebulosity in Orion, Herschel thought it probable that it lay between the distance of stars of the 7th magnitude, and extends perhaps to those of the 9th, 10th, and 11th magnitude. But even now, after more than a hundred years' further observations, we know little or nothing about the distance of gaseous nebulæ. Judging, however, from photographs of the Milky Way, it seems probable that some of these nebulosities are not farther from the earth than some of the stars visible to the naked eye.

Herschel mentions a number of other nebulous areas—one preceding ξ Cygni, covering about four square degrees; one near 125 Tauri; another preceding α Trianguli; one preceding 45 Eridani;

---

[1] Now called Uranus.

and one, in parts pretty bright, following 57 Cygni.

Herschel thought that a consideration of these nebulous stars and diffused nebulosities helps to explain the real nature of "planetary" nebulæ, which, he suggests, consists of "a much condensed luminous fluid." He considered the origin of this luminous matter as doubtful, but says, "Let it suffice that its existence is rendered evident by means of nebulous stars." This interesting paper shows clearly that Herschel's views of the nature of irresolvable nebulæ had completely changed in the year 1791.

In a paper on "The Nature and Construction of the Sun and Fixed Stars" in the *Philosophical Transactions* for 1795, Herschel says, "That stars are suns can hardly admit of a doubt. Their immense distance would perfectly exclude them from our view, if the light they send us was not of the solar kind." The same opinion was expressed by Thomas Wright, of Durham, in 1750, and it was evidently known to Shakspere, who lived over 100 years before Wright's time, for he makes Hamlet say in a letter to Ophelia—

> "Doubt thou the stars are fire;
> Doubt that the sun doth move;
> Doubt truth to be a liar;
> But never doubt I love."

Herschel thought that the fluctuations of light in the variable stars Algol, β Lyræ, δ Cephei, η Antinoi (η Aquilæ), and *o* Ceti are due to rotation on their axes; but this view is not now held by astronomers, the variations of light in the stars mentioned—with the exception of *o* Ceti—being probably caused by the revolution of dark or bright bodies round them. Herschel thought that all the stars had spots like the sun, and this seems very probable. Some of the red stars show a spectrum very similar to that of a sun spot. Herschel's opinion that the sun might possibly be inhabited is very surprising. He says, "We need not hesitate to admit that the sun is richly stored with inhabitants." But such an hypothesis would now be considered absurd. The sun is more probably gaseous to its centre, and its internal heat is probably greater than that of its surface. Herschel thought it probable that many of the stars form the centre of systems of planets and satellites, like our solar system, but from this hypothesis he excluded the compressed clusters of stars, which he looked upon as rather "*lucid*, primary planets, connected together in one great system of mutual support." He thought that in such cases the "stars are united in such close systems as not to leave much room for the orbits of planets or comets;" and this seems a rational and very probable hypothesis.

In a paper on "The Method of observing the Changes that happen to the Fixed Stars; with some Remarks on the Stability of the Light of our Sun. To which is added a Catalogue of comparative Brightness for ascertaining the Permanency of the Lustre of Stars," Herschel gives observations of the relative brightness of stars visible to the naked eye. This catalogue was succeeded by others in subsequent volumes of the *Philosophical Transactions*, and these catalogues are useful for comparison with modern estimates and photometric measures of star magnitudes. In the introduction to the first of these catalogues, Herschel says, "The hypothesis of an equality and an equal distribution of stars, to which we have referred, is too far from being strictly true to be laid down as an unerring guide in this research. The stars of the first and second class, when scrupulously examined, evidently prove that, if we would be accurate, we must admit them, in some degree at least, to be either of different sizes, or placed at different distances. Both varieties undoubtedly take place. This consideration alone is fully sufficient to show that, how much truth soever there may be in the hypothesis of an equal distribution and equality of stars, when considered in a general view, it can be of no service in a case where great accuracy is required." These views are now known to be undoubtedly correct. The apparent brightness of the stars is no criterion of their distance, and depends as much on their absolute size and relative luminosity of their surface as on their distance from the earth. Herschel's remarks above quoted also show his gradual change of views with reference to the distribution of the stars in space.

In this paper he gives examples of Flamsteed's estimates of star magnitudes, showing that some stars which he marked as brighter than others are in reality fainter, and conversely. These errors were, he thought, due to the fact that Flamsteed "did not compare the stars to each other, but referred each of them to its own imaginary standard of magnitude." This is evidently the correct explanation of the various estimates we find in some catalogues. Although estimates made in this way have some value, considerable allowance must be made for these discrepancies. Herschel says, "We can hardly allow less than half a magnitude in the higher orders [that is in the brightest stars], and a whole one in the inferior classes, for this uncertainty."

Herschel's own method was to compare the stars directly with others of a similar brightness in their vicinity, and this is the method now adopted by modern observers of variable stars. The rotation CDE would denote that C was brighter than D and D brighter than E. The relative brightness of C may be found by BCD, and that of B by ABC. We thus obtain a series ABCDE, etc., in which A is the brightest star, B a little fainter, and so on. This is now known as the method of "sequences."

Herschel points out that the Greek letters—given to the brighter stars by Bayer in 1603—do not represent the relative brightness of the stars in each constellation. Even α, β, and γ are not always in the order of brightness. If Bayer had affixed these letters correctly in order of relative brightness, he would have done a really useful work, and would have gained for himself an immortality to which he is not now entitled.

The method of sequences mentioned above not being considered by Herschel sufficiently delicate to give the relative brilliancy of the stars with sufficient accuracy, he adopted the following method. If two stars were estimated to be equal, or nearly so, he placed a point between them ; thus—

30 , 24 Leonis

30 being placed first as being possibly *very* slightly brighter than 24. When two stars are equal, but one of them just perceptibly brighter than the

other, their relative brightness is expressed by a comma, and the observation is written thus—

41 , 94 Leonis

which means that 41 Leonis is just perceptibly brighter than 94 Leonis. A greater difference in brightness between two stars is shown by a short line; thus—

17 – 70 Leonis, or 68 – 17 – 70 Leonis

Professor Pritchard finds that the sign · represented about 0·09 of a magnitude; , about 0·19 mag.; and – about 0·40 mag.

A much greater difference is expressed by two short lines; thus—

32 – – 41 Leonis

A still larger difference in brightness is represented by three short lines; thus—

16 – – – 29 Bootis

But this difference must be considered too large to be of any "use in estimations that are intended for the purpose of detecting change."

With reference to the known variation in the light of certain stars, Herschel says, "If it be allowed to admit the similarity of stars with our sun as a point established, how necessary will it be to take notice of the fate of our neighbouring *suns*, in order to guess at that of our own! That *star*, which among the multitude we have dignified by the name *sun*, to-morrow may slowly begin to undergo a gradual decay of brightness, like β Leonis, α Ceti, α Draconis, δ Ursæ Majoris, and many other diminishing stars that will be mentioned in my catalogues. It may suddenly increase, like the wonderful star in the back of Cassiopeia's chair, and the no less remarkable one in the foot of Serpentarius; or gradually come on like β Geminorum, β Ceti, ζ Sagittarii, and many other increasing stars." Herschel suggests that the changes in the earth's climate—which are clearly indicated by the geological records—may possibly have been due to changes in the sun. This seems highly probable. The sun, like other stars, is undergoing a slow processs of evolution, and far back in geological times—say ten millions of years ago—the sun's physical condition was almost certainly different from its present state. A study of the Carboniferous, or coal period, shows that the sun was probably hotter or of larger volume then than it is now; and going still farther back, we should reach a stage in which the earth's surface was so hot that life would have been impossible on its surface.

Herschel then gives the results of his comparison of the relative brightness of the stars in a number of constellations, to which is appended a series of notes on stars possibly variable, and others. These observations were very carefully made, and are still valuable for comparison with modern estimates and photometric measures. Speaking generally, I find that they agree well with modern observations. There are, of course, some discrepancies, and these give rise to a suspicion of variation in certain stars. A second catalogue is given in the *Philosophical Transactions* for 1796 (p. 452), a third in the volume for 1797 (p. 293), and a fourth in that for 1799 (p. 121).

In some introductory remarks to the second catalogue he gives his observations of the variable star α Herculis. He found a period of "somewhat more than two months' duration;" but modern observations do not quite confirm this result. The variation seems to be irregular. He refers to the probable rotation of stars on their axes as a possible cause of light variation, large portions of the surface being supposed to be covered with dark spots—like the well known sun-spots. But this hypothesis of *rotation* is not now considered as probable. The variations of long period are more probably due to internal changes in the body of the star. These changes may possibly give rise to large sun-spots, but these spots would probably be developed at a *maximum*, and not a minimum, of light. Some of the red stars show a spectrum very similar to that of a sun-spot. The variation of short period has been shown by the spectroscope to be due to the revolution of two bodies round their centre of gravity, which either produce eclipses—as in the Algol variables—or give rise to periodical disturbances by tidal action.

In the preface to the third catalogue of "The Comparative Brightness of the Stars," he gives an account of a careful examination of Flamsteed's catalogue and observations, made by his sister, Miss Caroline Herschel, and finds the following results.

1. There are 111 stars in Flamsteed's catalogue (the British catalogue, at it is called) which were never observed by Flamsteed, and he says, "This will explain why so many stars in the heavens seem to have been lost."

2. There are 39 stars in Flamsteed's catalogue

whose positions are incorrectly given. In some cases the error amounts to several degrees.

3. There are 54 stars in Flamsteed's *Atlas Cœlestis* which are erroneously placed ; some to the extent of many degrees.

4. There are 42 stars which must be reduced to 21, owing to some of them having "two names in different constellations."

5. There are 371 stars which, although observed by Flamsteed and their positions recorded, have been overlooked by Flamsteed in forming his catalogue.

6. There are 35 more stars of which the positions were doubtful, and have been omitted.

7. There are 86 stars with only the polar distance, and 13 with only the right ascension recorded, and these have been omitted.

8. Fifty more stars have been neglected, so that "upon the whole between five and six hundred stars observed by FLAMSTEED have been overlooked when the British catalogue was formed."

"A Fourth Catalogue of the Comparative Brightness of the Stars" appeared in the *Philosophical Transactions* for 1779. Two other similar catalogues were formed, but were not published by Herschel. These, however, were found among his papers at Collingwood in 1883, by Professor E. C. Pickering, of Harvard Observatory (U.S.A.), who has discussed and reduced all these catalogues in volumes xiv. and xxiii. Part II. of the *Harvard Annals*. A complete catalogue of all the stars observed by Herschel is given in the latter volume. The comparison between Herschel's estimates and the Harvard photometric measures is in most cases satisfactory, the average difference for all the stars being only ± 0·16 of a magnitude. Pickering says, "The error of a single comparison but little exceeds a tenth of a magnitude," and "the general accordance of the results renders the deviation of individual stars important as indicating secular variations." These results show the valuable results which may be obtained by careful estimations made with the eye without the assistance of any photometer.

In the *Philosophical Transactions* for 1800 there is a paper by Herschel, "On the Power of penetrating into Space by Telescopes: with a Comparative Determination of the Extent of that Power in Natural Vision, and in Telescopes of Various Sizes and Construction; illustrated by Select Observations." In this interesting paper he discusses "the method of vision at a distance." He shows that "light, flame, and luminous gases are penetrable to the rays of light." This he proved by an experiment, in which he placed four candles exactly in a line behind a screen, and opposite a narrow slit in the screen, $\frac{2}{3}$ of an inch long and $\frac{1}{4}$ inch wide. Lighting first one candle, the nearest to the screen, then the second, the third, and the fourth, he found that all four candles gave considerably more light than a single candle. From this he concludes that the sun's disc cannot be uniformly bright "on account of the unequal depth of its luminous atmosphere in different places." This is now known to be the case, the centre of the sun's disc being considerably brighter than the portions near the limb.

He speaks of "the copiousness of the emission of light from every physical point of the luminous surface" of a body emitting light. This corresponds with what I have elsewhere termed the luminosity of the surface—that is, the light emitted by a luminous body per unit of area. Calling C "the mean copiousness of light," N the number of points or area of the luminous surface, and L the total light emitted, Herschel says $CN = L$. This is obvious. But he adds, "If, however, there should at any time be occasion for distinction, the brightness arising from the great value of C may be called the intrinsic brightness; and that arising from the great value of N the aggregate brightness; but the absolute brightness, in all cases, will still be defined by CN." I lay particular stress on this point, as some writers have created a confusion between the total or "absolute brightness" (Herschel's L) and the "intrinsic brightness" (Herschel's C), or luminosity of surface, as I have called it.[1] Herschel then proceeds to consider the portion of the total light "which is used in vision either by the eye or by the telescope," and this he calls l. In this case "the equation of light in this present sense" will be $CN = l$. And since the "density of light" diminishes as the square of the distance, we have its quantity for a distance $D = \frac{l}{D^2}$.

Speaking of the increased sensibility of the eye by keeping it for some time in the dark, he says, "I remember that, after a considerable sweep with the 40-feet instrument, the appearance of Sirius announced itself, at a great distance, like the dawn of the morning, and came on by degrees increasing in brightness, till the brilliant star at last entered the field of view of the telescope, with all the splendour of the rising sun, and forced me to take the eye from that beautiful sight."

---

[1] One writer has accused me of inaccuracy in using the term "intrinsic brightness," the very term used by Herschel himself to express the same meaning.

Herschel says, "It may be remembered that I have distinguished brightness into three different sorts. Two of these, which have been discriminated by *intrinsic* and *absolute* brightness, are, in common language, left without distinction." The brightness referred to by mathematicians is the *intrinsic* brightness, and "this is the only meaning it can bear in the mathematician's theorem." With reference to the sun as seen from Saturn, he says, "The sun on Saturn appears to be a hundred times less than on the earth ; and that consequently, though it may there be *intrinsically* as bright, it must here be *absolutely* an hundred times brighter." Herschel also uses the term *intensely* illuminated for *intrinsic* brightness. The same view, he says, applies to the stars, and "their absolute brightness must vary in the inverse ratio of the squares of their distances." The visibility of the stars depends on the "penetrating power" of telescopes.

With reference to the power of naked-eye vision, he says that "the Georgian planet" (Uranus) is the farthest object that has ever been seen by *reflected* light. Assuming that stars of the second magnitude (α Cygni, β Tauri) are at double the distance of those of the first magnitude, if l be the brightness of a first-magnitude star, $\frac{1}{4}l$ will be the brightness of a second-magnitude. He thought that the sun is 170,000 million times brighter than Sirius. But this estimate is much too high. It would make the sun's stellar magnitude about $-29{\cdot}6$. Taking its value at $-26{\cdot}5$, which cannot be far from the truth, I find that the sun is about 9290 million times brighter than Sirius, so that Herschel's estimate was over eighteen times too large. A third-magnitude star ("pole star, γ Cygni, ε Bootis") he assumes to be at three times the distance of a first-magnitude. This would give a ratio of brightness between a second and third magnitude star of 9 to 4, or $2\frac{1}{4}$ to 1, instead of 4 to 1, the ratio between a first and second magnitude. Between a sixth and seventh magnitude star he finds a ratio of only a "little more than $1\frac{1}{3}$ to 1." But in modern photometry the ratio between all successive magnitudes is supposed to be the same, and is now generally assumed to be 2·512. Herschel's estimates of relative distance were mere assumptions, and we now know have no foundation in fact. Sirius is at about double the distance of α Centauri, although Sirius is a much brighter star.

From the faintness of stars of the seventh magnitude, Herschel concludes that "no star eight, nine, or at most ten times the distance of Sirius," can possibly be perceived by the naked eye. But this would not now be admitted by astronomers. For if Sirius were removed to ten times its present distance, its light would be reduced 100 times, or five magnitudes, and as the photometric magnitude of Sirius is $-1·6$, it would then be reduced to $5-1·6$, or 3·4 magnitude. Taking three magnitudes below this as the limit of naked-eye vision, it follows that Sirius might be removed to nearly forty times its present distance before it became invisible without a telescope. Arcturus is probably fifteen times farther from the earth than Sirius, and yet it is one of the brightest stars in the heavens.

Herschel refers to the visibility of some star clusters which are visible to the naked eye, although their components are only visible in a good telescope. Among these he mentions the double cluster in Perseus, Messier 35 in Gemini, and Messier 13 between η and ζ Herculis. He also refers to the great nebula in Andromeda (Messier 31).

Proceeding from "the power of penetrating into space by natural vision" to that by telescopes, he says the natural proportion would be as A to a, A being the aperture of the telescope and a that of the pupil of the eye. But an allowance must be made for the loss of light by reflection from mirrors and the absorption of light in the lenses of refracting telescopes. He made some experiments with plain mirrors to test this point, and found that out of 100,000 incident rays—that is, light rays falling on the mirror—67,262 were reflected, and therefore, with a double reflection, "only 45,242 would be returned." With reference to absorption in the eye-glass of a telescope, he found that out of 100,000 incident rays, 94,825 were transmitted through a single lens, and hence 89,918 through two lenses, and 85,265 through three lenses. Compounding this with the result found for reflection, he found that for a telescope of his construction (the "front view") 63,796 rays out of 100,000 were, with one reflection, received by the eye, and with the Newtonian form with a single-eye lens 42,901, and with a double eye-glass, only 40,681 rays reached the eye. These experiments were made, of course, with metallic mirrors. With modern "silver on glass reflectors," and improved eye-pieces, much better results would probably be obtained.

Herschel then proceeds to "find a proper expression for the power of penetrating into space, that we may be enabled to compare its effects in different telescopes with that of the natural eye." The penetrating power, he says, must be as the square roots of the lights received by the eye. For the naked eye this is expressed by $\sqrt{a^2 l}$. In the Newtonian form of telescope there is some loss of light in the second reflection from the small mirror. If b be the diameter of the small mirror, we have for the incident light $A^2 - b^2$, and correcting for the value x found above, we have the general expression—

$$\sqrt{xl(A^2 b^2)}$$

for the same power in telescopes. For refracting telescopes—and in reflecting telescopes with only one reflection (as in Herschel's "front view")—$b = 0$. Then, putting the natural light, $l = 1$, we have the general form—

$$\frac{\sqrt{x(A^2 - b^2)}}{a}$$

"for the penetrating power of all sorts of telescopes, compared to that of the natural eye as a standard." In his subsequent investigations, Herschel assumed a, the aperture of the pupil, to be two-tenths of an inch (that is, one-fifth of an inch), when the eye is in darkness. He then discusses the powers of his own instruments. He tried a 12-inch reflecting telescope of the Newtonian form on a distant church steeple, and found he could read the clock on the steeple, although the steeple itself was invisible to the naked eye in the dusk of the evening. He shows that this is a good example of increase of *absolute* brightness, the *intrinsic* brightness of the clock face being actually reduced in the ratio of 7 to 3.

Herschel used some very high powers for the observation of double stars. He states that these powers ranged from 460 to 6652.[1]

He gives some observations of nebulæ showing the space penetrating powers of his telescopes. With a 10-feet reflector (that is, of 10 feet focal length), and a space penetrating power of 28·67, he found the cluster Messier 5 (near 5 Serpentis) beautifully resolved into stars. A 7-feet telescope, with a space penetrating power of about 20, failed to resolve it.[2] Other telescopes and clusters gave similar results. With the 40-feet telescope used as a "front view," he saw the 4th satellite of Saturn [Dione] and the ring "without an eye-glass." With this telescope he discovered "the 6th satellite of Saturn" [Enceladus, now called the 2nd] on August 28, 1789, and the "7th satellite" [Mimas, now known as the 1st] on September 11 of the same year. The 20-feet reflector showed both these satellites *after* their discovery, but the 7-feet and 10-feet reflectors failed to show them.

The 40-feet telescope had a space penetrating power of 191·69. To obtain a space penetrating power of 500, Herschel computed, would require a telescope of 10 feet 5·2 inches in diameter for a reflector on his construction. But he points out that the light of the heavens on a clear night would set

---

Phil. Trans., 1800, p. 70, footnote.

[2] With the 40-feet telescope, giving a space penetrating power of 191·69, he counted 200 stars in this cluster, "but the middle is so compressed that it is impossible to distinguish the stars." A photograph by Dr. Roberts confirms Herschel's result.

a limit to the faintness of the smallest stars visible. For, he says, the sky light "must in the end be so increased by enlarging the penetrating power, as to become a balance to the light of all objects that are so remote as not to exceed in brightness the general light of the heavens." This is an interesting and important remark of Herschel's. Dr. Roberts found that stars of the 18th magnitude are probably the faintest which could be photographed, for the reason assigned by Herschel.

Combining the above results for the space penetrating power of his smaller telescope with the length of the "sounding line" deduced from the "star gages," Herschel concluded that this telescope would show stars 571 times as far from the earth as Sirius, "and only those 653, 734, and 816 times the same distance would have been beyond its reach." Let us see how these distances compare with the results of modern observations and telescopes. The 40-inch telescope of the Yerkes Observatory shows stars to about the 17th magnitude of the modern photometric scale. Now, as the magnitude of Sirius is $-1{\cdot}58$, it is 18·58 magnitudes, or about 27,000,000 times brighter than a star of the 17th magnitude. Hence it follows that if Sirius were removed to 5200 times its present distance ($\sqrt{27{,}000{,}000}$), it would still be visible as a faint star in the great Yerkes telescope. Herschel says that, taking the space penetrating power of his 40-feet telescope as 192, and a 7th magnitude star as the limit of unaided vision, "this telescope would show stars of the one thousand three hundred and forty second magnitude." But there is some mistake here; for no telescope that could possibly be constructed would show stars of even the 100th magnitude (if any such exist). Probably Herschel intended to say that his 40-feet telescope would show stars 1342 times the distance of Sirius. But according to modern estimates, it would probably have shown stars much farther off than this, as the above results for the Yerkes telescope will show. Herschel shows that a cluster of 50,000 stars[1] would be visible in his large telescopes if its distance were 11¾ millions of millions of millions of miles."[2] But this result seems very doubtful, as it would imply a journey for light of two millions of years.

Herschel computes how long it would take to "gage" the whole heavens with the 40-feet telescope and power of 1000, allowing that a year will yield 100 hours suitable for the purpose, when the sky is very clear, the moon absent, no twilight, no haze, no violent wind, and no sudden change of temperature, and he finds that the heavens might be "swept" with his 20-feet reflector in about 14¾ years; but with the higher power used on the 40-feet telescope it would take no less than 498 years, and a further 213 years for the portion of the southern hemisphere invisible in these latitudes. But the application of photography to the heavens has overcome this difficulty, and the work can now be done much more accurately and quickly. The photographic chart of the heavens commenced some years ago is now approaching completion.

In the year 1802, Herschel published in the *Philosophical Transactions* for that year a "Catalogue of

---

[1] First stated as 5000, but afterwards corrected by Herschel to 50,000 (*Phil. Trans.*, 1802, p. 498, footnote).

[2] Herschel's number is equivalent to 11⅓ trillions of miles.

500 New Nebulæ [in addition to others previously published], Nebulous Stars, Planetary Nebulæ, and Clusters of Stars." In the introduction to this catalogue he makes some remarks on "the construction of the heavens." He says that the sun and solar system "can only rank as a single individual belonging to the species we are going to consider." Among what he calls "insulated stars," that is, "stars at immense distances from each other," he includes the Sun, Arcturus, Capella, Lyra [Vega], Sirius, Canobus, Markab [α Pegasi], Bellatrix, Menkar [α Ceti], Shedir, Algorab [α Corvi], Propus,[1] etc.

Taking the diameter of the earth's orbit round the sun as probably subtending not more than an angle of one second, as seen from Sirius,[2] he finds that, supposing the masses equal, the two bodies would not fall together in less than 33 millions of years. He thinks that such stars may be considered as "insulated," that is, not immediately connected with any neighbouring stars. He also thought that the opposite attractions of the surrounding Milky Way would tend to keep these insulated stars almost at rest. And here he makes an interesting remark on the Milky Way, which clearly shows his change of views on the construction of the Galaxy. He says, "For, though our sun, and all the stars we see, may truly be said to be in the plane of the Milky Way, yet I am now convinced by a long inspection and continued examination of it, that the Milky Way itself consists of stars very differently scattered from those which are immediately about us. But of this more will be said on another occasion." Here he practically abandons the "disc theory."

---

[1] Probably a misprint for Procyon.

[2] In other words, that the parallax of Sirius is less than half a second of arc. This we now know to be correct, the best measures of its parallax being 0·37 second.

He thought "that probably we can only look for solar systems among insulated stars," other sidereal constructions being perhaps differently constituted. The satellites of Sirius and Procyon were of course unknown to Herschel; but we can hardly call these solar systems. Planets they may possibly have, but the visible attendants are undoubtedly faint suns, and these bright stars are really binary systems, and not "insulated stars."

Herschel then considers the binary, or revolving double stars, and says, "there is an essential difference between the construction of solar and sidereal systems." He shows that "insulated stars," like Arcturus and Vega, could never appear double to us, for in order that they should seem close enough to rank as a double star, they should be removed to a distance of 41,253 times the distance of Sirius, and that at this great distance even the 40-feet telescope would fail to show them. This is evidently correct, for the distance given is about eight times the distance at which Sirius would be reduced to a star of the 17th magnitude. He considers the case of the double star ζ Aquarii which has components of nearly equal brightness, and shows that the odds are over $75\frac{1}{2}$ millions to one against the hypothesis that ζ Aquarii is merely an optical double star. Hence he concludes that the components of close double stars are really close together, and that "their existence must be owing to the influence of some general law of nature." This, he says, is confirmed by his own observations, which show that "*many of them have actually changed their situation with regard to each other, in a progressive course, denoting a periodical revolution round each other; and that the motion of some of them is direct, while that of others is retrograde.*"[1] He then considers treble, quadruple, and multiple stars, and shows that a number of bodies may revolve round an "empty centre" by the laws of gravitation, "and remain permanently connected without a central body." He considers various cases of three and four bodies of equal mass revolving round a common centre in equal times. But we do not find such simple cases in nature.

With reference to the Milky Way, he says, "On a very slight examination it will appear that this immense starry aggregation is by no means uniform. The stars of which it is composed are very unequally scattered, and show evident marks of clustering together into many separate allotments."[2] Here we have further evidence of Herschel's change of views.

He thought that "the construction of groups of stars is perhaps, of all objects in the heavens, the most difficult to explain." In the globular clusters he speaks of "a centre of attraction," round which the components revolve. This was also the opinion of his famous son, Sir John Herschel. With reference to the nebulæ, he thought that clusters at a great distance might present the appearance of nebulæ, but with instruments of high space penetrating power the latter "are the objects which may be perceived at the greatest distance." He considers that milky nebulosity may be either due to "widely extended regions of closely connected stars," or else real nebulosity at "possibly no very great distance from us." He thought that he had observed some changes in the great nebula in Orion, but modern observations do not tend to confirm this idea. Changes are doubtless in progress, but they probably take place very slowly.

---

[1] The italics are Herschel's.

[2] *Phil. Trans.*, 1802, p. 495.

With reference to "nebulous stars," he seems to think that the surrounding luminous haze is due to a "self-luminous milky nebulosity," although the central point of light is really a star. We now know that this is probably the correct conclusion. "Planetary nebulæ," he thought, "allied to nebulous stars," and the spectroscope has fully confirmed this hypothesis. He noticed that some of the planetary nebulæ showed a bright central point, and these he considered to be "an intermediate step between planetary nebulæ and nebulous stars." In this idea he was probably correct, the nebulous stars possibly indicating a more advanced stage in stellar evolution.

In the *Philosophical Transactions* for 1803 (p. 339) there is a paper by Herschel entitled, "Account of the Changes that have happened during the last Twenty-five Years in the Relative Situation of Double Stars; with an Investigation of the Cause to which they are owing." In this interesting paper we have the first recorded observations of motion in binary star systems. The probable existence of revolving double stars was previously predicted by the Rev. John Michell, but he made no observations in support of his theory, and to Herschel is due the *proof* by actual measurements. The first star considered by Herschel is α Geminorum or Castor, the northern of the two bright stars in the heads of the Twins. He estimated the distance between the components in the year 1778 to be about two diameters of the larger star, and 23½ years afterwards (in 1802) he found the distance about the same—that is, about five seconds of arc. The distance had therefore remained nearly constant. But not so the angle of position. This he found in 1779 to be 32° 47′ north preceding, measuring from the north point of the field of view. But in the year 1802 he found this angle to be only 10° 53′, so that in a period of about 23 years the angle of position had changed about 21° 54′, indicating an orbital revolution of one component round the other, or rather both round their common centre of gravity. This he shows must be the case, and that any other hypothesis, such as the proper motions of the stars, or the sun's motion in space, fails to explain the observed motion with any degree of probability. The famous Bradley had previously observed the position of the components of Castor about the year 1759, and found that the line joining them was "parallel to the line joining Castor and Pollux in the heavens, seen by the naked eye." This observation Herschel found represented a position angle of 56° 32′. This would indicate a total change of 45° 39′ in a period of about 43½ years. From this motion Herschel computes that the period of revolution of one component round the other would be about 342 years. This result agrees closely with the most recent orbit computed by Dr. Doberck, who finds a period of 346·82 years. The total change of angle now amounts to over 100° since Bradley's time.

Herschel then considers the motion of the double star γ Leonis. For this pair he found a motion of 13° 58′ in 21 years, with a small increase in the distance. From the observed measures he concluded that the period of revolution was about 1200 years. Three orbits have been computed for this star—one by Hind, and two by Doberck; but Burnham has shown that all the measures may be fairly well represented by rectilinear motion, and hence that the binary character of the pair is doubtful.

Another star mentioned by Herschel is the beautiful double star ε Boötis. Here he found an angular motion of 12° 33′ in about 22½ years, with a slight increase in the distance, and he concludes that the period of revolution would be about 1681 years. But modern measures do not quite confirm this result, the motion, if any, being very slow.

With reference to ζ Herculis, now a well-known and interesting binary, Herschel says that his observations "furnish us with a phenomenon which is new in astronomy; it is the occultation of one star by another." In 1802 he found it apparently single, with a high power, and concluded that one star was eclipsing the other. But recent investigations of the orbit of this star, which has a period of about 35 years, show that no real occultation ever takes place, the minimum distance between the components being, according to Dr. See, about 0·45 second.

For δ Serpentis, Herschel found an angular change of 18° 39′ in about 19 years, and estimates the period of revolution at about 375 years. But measures in recent years show that the motion is now very slow, and its binary character seems to be doubtful.

For the famous binary star γ Virginis, Herschel found an angular change of 10° 24′ in about 21⅓ years, with little or no change in the distance. An observation by Mayer in 1756 gives a position angle of 54° 21′ 37″, showing a total change of 24° 2′ in about 47 years. From these observations Herschel estimated the period of revolution at about 708 years; but the best modern orbit gives a period of 194 years (See).

In a second paper on the subject of binary stars in the *Philosophical Transactions* for 1804, Herschel considers a number of other double stars in which he thought he had detected angular motion. Some of these have proved to be binary, but in others the motion has not been confirmed.

In the volume for 1805 (p. 233) Herschel describes further investigations made with a view to determine the direction and velocity of the sun's motion in space. He points out that if a solar motion exists, all the apparent parallactic motions will be in a direction opposite to that of the sun's motion, but the real motions of the stars themselves will take place "indiscriminately" in all directions. He then considers the motions of some of the brighter stars —as probably the nearest to the earth. He finds that when the lines representing the proper motions of these stars are produced backwards, they meet in various points in Hercules, and near "the head of the Dragon" (Draco). Taking stars of the second magnitude, and combining these with the first, he finds a very similar result. He thought that the changes in the position of the components of some double stars was probably due to the sun's motion in space.

In a third paper on the same subject in the

Philosophical Transactions for 1806 (p. 205), Herschel continues his examination of the subject, and assumes that, roughly, the distances of the stars are indicated by their brightness, the brightest being the nearest. He gives the relative brightness of the brightest stars thus (in his notation described above)—

Sirius – – – Arcturus – Capella –, Lyra – – Aldebaran . Procyon.

Here he estimates Aldebaran as equal to, or even slightly brighter than, Procyon, but modern photometric measures make Procyon the brighter by about half a magnitude. He gives the following "Proportional Distances":—

Sirius . .	1·00	Lyra (Vega) .	1·30
Arcturus .	1·20	Aldebaran .	1·40
Capella .	1·25	Procyon . .	1·40

But modern measures of parallax give the actual distances of these stars in the following proportion:—

Sirius . .	1·00	Vega . . .	4·51
Arcturus .	15·41	Aldebaran .	3·46
Capella .	4·56	Procyon . .	1·14

This shows how unsafe it is to estimate distances of stars by their apparent relative brightness.

Herschel shows that the proper motions of the stars cannot be accounted for by orbital motion round each other. He then discusses the hypothesis of a central body of great size, which he thinks might possibly exist, but must be considered as "intirely hypothetical." A very massive body at a centre of force might, however, be replaced by a group of stars, whose combined attractions might produce the same effect, and he refers to a cluster discovered by Halley, which seems to be the great globular cluster in Hercules (Messier 13). He does not, however, limit this hypothesis to *one* cluster, but thought that the combined attractions of a number of clusters might have the observed result. A further source of attraction might, he suggested, be found in the clustering regions of the Milky Way. He did not arrive at any very definite conclusion as to the position of the supposed centre of attraction, but seemed convinced that the proper motions of the stars and the sun's motion in space must be due to some form of gravitation.

In a paper in the *Philosophical Transactions* for 1811 (p. 269) Herschel returns to the subject of the construction of the heavens. He says, "A knowledge of the construction of the heavens has always been the ultimate object of my observations," and he proposes to arrange the objects he observed "in a certain successive regular order." He uses the following memorable words, which show his change of views since the publication of his earlier papers on the subject: "If it should be remarked that in this new arrangement I am not entirely consistent with what I have already in former papers said on the nature of some objects that have come under my observation, I must freely confess that by continuing my sweeps of the heavens, my opinion of the arrangement of the stars and their magnitude, and of some other particulars, has undergone a gradual change; and indeed when the novelty of the subject is considered, we cannot be surprised that many things formerly taken for granted should on examination prove to be different from what they were generally, but incautiously, supposed to be. For instance, an equal scattering of the stars may be admitted in certain calculations, but when we examine the Milky Way, or the closely compressed clusters of stars, of which my catalogues have recorded so many instances, this supposed equality of scattering must be given up. We may also have surmised nebulæ to be no other than clusters of stars disguised by their great distance, but a larger experience and better acquaintance with the nature of nebulæ will not allow a general admission of such a principle, although undoubtedly a cluster of stars may assume a nebulous appearance when it is too remote for us to discern the stars of which it is composed."

He then proceeds to divide the celestial objects he observed into "classes," as follows:—

1. "Extensive diffused nebulosity." This can only be seen with telescopes of great light gathering power. Modern photographs show this diffused nebulosity in many parts of the Milky Way and elsewhere. Herschel gives a list of 52 places where he observed such faint nebulosity. Photographs taken by the late Dr. Roberts of Herschel's nebulous regions failed to reveal this nebulosity, except in four cases; but photographs by other astronomers have shown nebulosity in several of the places indicated by Herschel. Herschel was such an excellent and cautious observer, it is difficult to imagine that he could have been deceived in this matter. His 52 nebulous regions covered an area of nearly 152 square degrees. He says, "By nebulous matter I mean to denote that substance, or rather those substances which give out light, whatsoever may be their nature, or of whatever different powers they may be possessed."

2. "Nebulosities joined to nebulæ." He found that the diffused nebulosity just mentioned is sometimes connected with "real nebulæ." Among examples of this class he mentions the great nebula in Orion, and he says "we can hardly have a doubt of its being the nearest of all the nebulæ in the heavens." But this now seems doubtful. The stars in its vicinity, and which are probably connected with it, show no signs of any measurable parallax. He says that this nebula contains very bright and also very faint nebulous matter, and argues that the fainter portions cannot be "exceedingly farther from us" than the brighter parts.

3. "Detached nebulosities." These are small detached portions of nebulous light visible in some parts of the sky.

4. "Milky nebulæ." This term he applies to small detached nebulosities which have a "milky light."

5. "Milky nebulæ with condensations." These objects have a slightly brighter centre, and Herschel thought this might be due either to condensation or to increased depth of the nebulous matter in the line of sight.

6. "Nebulæ which are brighter in more than one place." There are nebulæ which have more than one nucleus or condensation of light. Herschel thought that these objects tend to show that the nuclei are due to condensation, and not to increased thickness of nebulous matter. For the latter hypothesis would necessitate the assumption of "very slender and deep projections, all situated exactly in the line of sight," and such an arrangement would, of course, be highly improbable. Assuming that the nuclei are due to

condensation of nebulous matter in the brighter portions of these nebulæ, he shows that they are most probably due to "the universal gravitation of matter," and this view is clearly the correct one.

7. "Double nebulæ with joined nebulosity." These are small nebulæ, each with a nucleus, and connected by a nebulous band. Herschel thought that they were on the verge of splitting into two, and that some had actually separated. Of the objects observed by him some were less than two minutes of arc from each other. The majority, however, were further apart—up to 10 minutes. Most of these differ but little in brightness, showing that probably they are at about the same distance from the earth.

8. "Treble, quadruple, and sextuple nebulæ." In addition to the double nebulæ mentioned above, Herschel observed twenty treble, five quadruple, and one sextuple nebulæ. Among these he mentions a quadruple nebula, in which four nebulæ lie within three minutes of arc. The nebulæ in the sextuple one "are all very faint and very small." He thought that these compound nebulæ probably owe their origin to "the breaking up of some former extensive nebulosities of the same nature." He notes that there are regions where the nebulæ of his catalogues "are uncommonly crowded." One of these regions begins "over the tail of Hydra and proceeding to the southern wing, the body, and the northern wing of Virgo. Then to Coma Berenices, Canes Venatici, and the preceding arm of Bootes. A different branch goes from Coma Berenices to the hind leg of Ursa Major. Another branch passes from the wing of Virgo to the tail and body of Leo." The existence of this nebulous region has been fully confirmed

by modern observations. An "absence of nebulæ," Herschel says, is remarkable in a region extending from the head of Capricornus, through Antinous, to the tail of Aquila, and through the body of Hercules to the head of Draco. There is also a barren region in Auriga, Lynx, and Camelopardalus.

9. "Very narrow long nebulæ." These, Herschel thought, were nebulæ of small thickness seen edgeways. Modern observations suggest that most of these elongated objects are spiral nebulæ with their edges turned towards the earth.

10. "Extended nebulæ." These are similar to the last, but of greater apparent width. Most of them probably represent spiral nebulæ seen at various high angles of inclination. But Herschel was not aware of the existence of spiral nebulæ. They were discovered by Lord Rosse with his great 6-feet reflector, and photographs have fully confirmed their existence.

11. "Nebulæ of an irregular figure." This is a term applied by Herschel to small nebulæ with no well-marked boundaries. The term might also be applied to the great nebula in Orion and others of the same character.

12. "Nebulæ of an irregular round figure." These he considered as probably spherical in form, and not cylindrical or conical. As in the latter case the axis of the cylinder or cone must point exactly towards the earth, the probability is, of course, in favour of the globular form.

13. "Round nebulæ." These are of a more definite circular form, and Herschel considered them globular, and says, "we may now more confidently assign the attraction of gravitation as the principle which has

drawn the nebulous matter towards a center, and collected it into a spherical compass."

14. "Nebulæ that are remarkable for some particularity in figure or brightness." Among these he mentions "a considerably bright nebula about 15 minutes long and 3 minutes broad; its length is divided in the middle by a black division at least three or four minutes long," and he suggests that it is "a ring in a very oblique position with respect to the line of sight." Here, again, we have probably a spiral nebula with its plane at a high angle to the background of the sky.

15. "Nebulæ that are gradually a little brighter in the middle." This increase of brightness is "always very gradual from the outside towards the middle of the nebulæ." This he thought probably due either "to the small quantity of the preponderating central attractive power, or even to the shortness of its time of acting; for in this case "millions of years perhaps are but moments."

16. "Nebulæ which are gradually brighter in the middle." This class includes those nebulæ in which the increase of light in the centre is decidedly greater than in the preceding class. Herschel thought that the gravitating action was here "in a more advanced state," or, in modern language, that these objects are in a more advanced stage in the evolution of stars from nebulæ.

17. "Nebulæ that are gradually made brighter in the middle." These seem to show a further step in the condensation process—that is, a more advanced stage of evolution.

18. "Nebulæ that have a cometic appearance." In this class Herschel included nebulæ with a strong

condensation in the centre, thus resembling a telescopic comet, and he suggests that small comets "may be composed of nebulous matter, or may, in fact, be such very highly condensed nebulæ." But even the smallest of these nebulæ must be vastly greater in size than the largest comet ever observed.

19. "Nebulæ that are suddenly much brighter in the middle." In this class the nucleus is more sharply marked from the surrounding nebulosity than in the preceding class. In fact, they are more like "nebulous stars," except that the nucleus is a nebula, not a star. Herschel thought that this nucleus was an indication of approaching consolidation.

20. "Round nebulæ increasing gradually in brightness up to a nucleus in the middle." Here we have clear evidence of "the existence of a central attraction." They seem to closely resemble what Herschel called "cometic nebula."

Of "nebulæ with a nucleus" Herschel mentions Messier 63. A photograph by Dr. Roberts in 1896 shows this to be a spiral nebula "with a bright stellar nucleus in the centre of dense nebulosity." Huggins finds a continuous spectrum, indicating, as Herschel supposed, an advanced stage of condensation.

Among "extended nebulæ that show the progress of condensation" Herschel mentions Messier 65, which he describes as "a very brilliant nebula extended in the meridian, about 12 minutes long. It has a bright nucleus, the light of which suddenly diminishes on its border, and two opposite very faint branches." A photograph by Dr. Roberts shows that this is also a spiral nebula.

Herschel observed some small nebulæ of "an almost uniform light." These seem to differ but little from the "planetary nebulæ." Some of these objects, he thought, were approaching "a period of final condensation." This, he considered, was shown by the fact that they seem to have "a superficial lustre such as opaque bodies exhibit, and which could not happen if the nebulous matter had no other quality than that of shining, or had so little solidity as to be perfectly transparent."

With reference to "planetary nebulæ," he considered that these objects are considerably compressed from their original condition. Their usually small apparent diameter of 10 seconds to 60 seconds suggests that they have condensed considerably, and that a still further condensation would terminate in the production of a star. He shows that the density of nebulous matter must be very small, and that "a cubical space, the side of which at the distance of a star of the 8th magnitude is seen under an angle of 10 minutes, exceeds the bulk of the sun over two trillion times." But as the distance he assumed for an 8th magnitude star is much less than the distance now supposed, his figures—enormous as they are—should be largely increased. Herschel thought that these planetary nebulæ probably rotated on an axis. This, he says, is indicated by their form, seven out of ten, he observed, being "not perfectly round, but very little elliptical." Other nebulæ also show a tendency to a similar form.

He then discusses the probable distance of the great nebula in Orion. Supposing it to be at the same distance as small stars near it, he comes to the conclusion that the distance of the faintest parts of this vast nebula "cannot well exceed the region of stars of the 7th or 8th magnitude, but may be much nearer; perhaps it may not amount to the distance of stars of the 3rd or 2nd order." But even now the distance of this wonderful nebula is quite uncertain. Herschel thought he found changes in the nebulosity in the course of 37 years' observation. But such changes have not since been confirmed with any certainty. Probably changes are in progress, but these may take place very slowly. Even a hundred years would hardly count in the life of a nebula.

He gives a number of examples of what he terms "stellar nebulæ." These are usually very small, and might be easily mistaken for stars with telescopes of moderate power. He thought that these objects might possibly be planetary nebulæ "in a higher state of condensation." In some doubtful objects—about 34 in number—he could not satisfy himself whether the object was really a star or a small nebulæ. Finally, he concluded that he had found in the heavens examples of all stages of evolution, from the purely nebulous one down to the strictly stellar type.

In the *Philosophical Transactions* for 1814 Herschel again returns to the same subject. But in this paper he considers what he calls "the sidereal part of the heavens," and the apparent connection between stars and star clusters and nebulous matter. He divides these objects into classes as before.

1. "Stars in remarkable situations with regard to nebulæ." These are stars connected, apparently at least, with faint nebulosity. He suggests that some nebulæ "may have considerable proper motions by which they are carried towards neighbouring stars." But it now seems more probable that the

proper motion, if any, would be in the stars, not the nebulæ.

2. "Stars with nebulosity between them." These are stars (usually two) apparently connected by faint nebulosity. That this should happen by mere chance is, he argues, quite incredible.

3. "Stars with nebulosity of various shapes attached to them." In these objects the nebulosity is only on one side, apparently attached to the star, and making it look like a small comet. Here, again, a real connection between the stars and the nebulosity seems to be certain.

4. "Stars with nebulous branches." These are somewhat similar to those in class 1, above.

5. "Nebulous stars." These have been already described and discussed.

6. "Stars connected with extensive windings of nebulosity." These are stars apparently connected with irregular shaped nebulosity. With reference to these objects, Herschel makes the following interesting remarks, which show clearly his views on the subject in 1814, and prove that his ideas of the constitution of nebulæ had completely changed since his earlier papers were written:—

"The formation of these objects is extremely instructive, as it manifests the affinity between the matter of which stars are composed and that of the most unshapen chaotic mass of nebulosity. For the vanishing chevelure of a star being equally connected, on the one hand, with the generally diffused nebulous matter, and on the other with the star itself, round which it is in a state of gradual condensation; this double union denotes the mutual gravitation of the whole mass of nebulosity and the stars towards each other; and unless this proof can be invalidated, we must admit the fact of the growing condition of stars, that are in the situation which has been pointed out.

"This argument adds greatly to the probability of stars being originally formed by the condensation of the nebulous matter; for as it now appears that stars must receive an addition to their solid contents, when they are in contact with nebulosity, there is an evident possibility of their being originally formed of it. Moreover, the affinity between the nebulous and sidereal condition being established by these observations, we may be permitted to conceive both the generation and the growth of stars, as the legitimate effects of the law of gravitation, to which the nebulous matter, as proved by observation, is subject."

7. "Small patches consisting of stars mixed with nebulosity." These, he thought, might possibly be due to stars and nebulæ being "accidentally in the same line of sight," but that "the probability is in favour of a real union." He suggests that in some cases nebulosity might possibly drift by proper motion into a region of small stars, and then be "gradually arrested and absorbed by them," and that thus "the *growth of stars* may be continued."

He found some objects of "an ambiguous construction," the real character of which he could not well determine.

Herschel then proceeds to consider the stars themselves as distinguished from the nebulæ. He found that star clusters might be divided into different classes. But most of these classes seem to be included in two, namely, irregular clusters and globular clusters. Some of his irregular clusters contained stars of various sizes; some mostly large stars—that is, comparatively large; others contained extremely small stars only; some are coarsely scattered; others apparently much compressed. Among "clusters of a peculiar description" he mentions Messier 4 and 30. Among those "approaching the globular form" he refers to Messier 68. This was "clearly resolved into stars of 12th magnitude" by his famous son, Sir John Herschel. Among those he considered as certainly globular clusters, and which he calls "undoubtedly the most interesting objects in the heavens," he mentions Messier 72, containing, he estimated, hundreds of stars; Messier 2, in which he could see the stars "even in the central mass;" from its apparent magnitude, 7·7, as measured at Harvard, I find that it probably contains about 800 stars. Messier 5, 56, 80, 13, 3, 15, 79, 19, and 53, are all well-known globular clusters.

He then refers to "more distant globular clusters of stars." These he called "miniatures" of the larger globular clusters. Among these he mentions Messiers 9, 14, 62, and 75. He supposed these smaller objects to be at a greater distance from the earth, as their component stars are faint and closer together.

Among still smaller objects of the globular class he mentions Messier 69. This is a small globular cluster, about 2½° north, following ε Sagittarii.

With reference to the Milky Way, he says that in the constellations Sagittarius and Perseus there are "eighteen different shades of glimmering light." From this he infers that the Galaxy is gradually "breaking up," and he says, "we may also draw a very important conclusion from the gradual dissolution of the Milky Way; for the state into which the incessant action of the clustering power has brought it at present, is a kind of chronometer that may be used to measure the time of its past and future existence; and although we do not know the rate of going of this mysterious chronometer, it is nevertheless certain that, since the breaking up of the parts of the Milky Way affords a proof that it cannot last for ever, it equally bears witness that its past duration cannot be admitted as infinite."

In the *Philosophical Transactions* for 1817 there is a paper by Herschel[1] on "Astronomical observations and experiments tending to investigate the local arrangements of the celestial bodies in space, and to determine the extent and condition of the Milky Way." In this interesting paper he says that the position of a celestial body in space can be determined by three dimensions, which he calls "length, breadth, and depth; or longitude, latitude, and profundity," the last-named meaning, of course, the distance of the body from the earth. Of these the longitude and latitude can be easily found on a celestial globe or star atlas, but the distance from the earth cannot always be determined with any approach to accuracy. In some cases, of course, such as the sun, moon, and planets, their distance can be found and their exact position in space can be accurately ascertained. But the distances of the stars are so great that satisfactory results had not been obtained in Herschel's time. He supposed that the diameter of the earth's orbit would not subtend an angle of more than a second of arc at the distance of the nearest star, and this estimate is nearly correct, the largest parallax known being that of α Centauri, namely, 0·75 second (or 1·50 second for the diameter of the earth's orbit). He then refers to star magnitudes as some indication of the relative distance;[1] but he thought it safer to assume an equal scattering of the stars in space, and thus deduce their distance approximately. He supposes a series of concentric spheres with radii of 1, 3, 5, 7, 9, etc., and finds the number of stars which should be contained in each sphere on the assumption of equal distribution. The volumes of these spheres, and hence the number of stars in each, will be proportional to the cubes of the radii, or as 1, 27, 125, 343, etc., the differences being the number of stars in each shell included between two adjacent spheres. He then compares the numbers thus found with the number of stars of each magnitude as given in Bode's catalogue. This catalogue contains 17 stars of the 1st magnitude; but the number, according to Herschel's hypothesis, should be 26. Of 2nd magnitude stars, there are 57 stars in the catalogue, instead of 98 as in Herschel's arrangement. Of the 3rd magnitude there are 206 instead of 218; and of the 4th magnitude the catalogue shows 454, instead of only 386 on Herschel's plan. For the total number of stars in the 4th magnitude we have 735 in the catalogue, and 729 in Herschel's arrangement—a close agreement. The result is, however, not so satisfactory for the fainter stars. Thus the catalogue contains 1161 stars of the 5th magnitude, whereas "the 5th order of distances has only room for 602;" and "of the 6th magnitude the catalogue contains not less than 6103 stars,[1] but the 6th order of distances will admit of only 866 stars." For the 7th magnitude the catalogue "points out 6146 stars of the 7th magnitude, while the number of stars that can be taken into the 7th order of distances is only 1178."

---

[1] Here for the first time he calls himself *Sir* William Herschel, *Knt Guelp*, LLD., F.R.S.

---

[1] We now know that relative brightness is not a safe criterion of distance, some faint stars being nearer to us than many of the brighter stars.

Although admitting that brightness is not a certain test of distance, Herschel says, "The statement, however, that, one with another, the faintest stars are at the greatest distance from us, seems to me so forcible, that I believe it may serve for the foundation of an experimental investigation." He then explains a method of "equalizing the light" of two stars by means of two telescopes of equal diameter and focal length. These were placed side by side, and for a bright star the aperture of one was reduced by circular apertures until its apparent brightness became equal to that of a fainter star viewed with the other and full aperture.

"In the calculation of a set of apertures for the intended purpose," he admitted none that gave less than one-fourth of the light, as the "spurious" discs of the stars rendered an accurate estimate impossible. This method of limiting apertures has been sometimes used in modern times, but has now been superseded by photometers, which give more accurate results.

Herschel gives the results of some experiments he made by this method. Comparing Arcturus with α Andromedæ, he found that Arcturus was about four times the brightness of the other, so that "if Arcturus was put at twice its distance from us, it would then appear, like α Andromedæ, as a star of the 2nd magnitude, and it would also at the same time be really a star of the 2nd order of distances." According to the Harvard photometric measures, Arcturus is 0·24 and α Andromedæ 2·15 magnitude. This makes Arcturus 5·8 times brighter than α Andromedæ. Among other stars which he found had about one-fourth of the light of Arcturus, he gives the Pole Star, γ Ursæ, and δ Cassiopeiæ. The Harvard measures of these are 2·12, 2·54, and 2·80 respectively.

---

[1] We now know that this number of stars of the 6th magnitude is too large. The *total* number of stars *down to the 6th magnitude* is, according to the Harvard photometric measures, about 4340.

Taking α Andromedæ as a standard, he found that μ (Fl. 48) Pegasi is a star of the 4th magnitude. The Harvard measure of μ Pegasi is 3·67, or a little brighter than Herschel made it. Proceeding, then, from μ Pegasi as a standard, he found that *q* (70) Pegasi had one-fourth of the light of μ Pegasi, "and that consequently Arcturus, removed to 8 times its present distance from us, would put on the appearance of a star which in our catalogues is called the 5th or 6th magnitude, but which would, in fact, be of the 8th order of distances" (that is, on Herschel's scale of distances). As the Harvard measure of 70 Pegasi is 4·67, it follows that Arcturus is 4·43 magnitudes, or 59 times brighter than 70 Pegasi, and as Herschel makes it 64 times (8^2) brighter, his result agrees well with modern photometric measures.

Starting from Capella, he found that one-fourth of its light would represent the brightness of β Aurigæ and β Tauri. The Harvard measures make Capella

4·25 times brighter than β Tauri and 5·55 times brighter that β Aurigæ. He found that β Tauri was 4 times brighter than ζ Tauri and ι Aurigæ, but the Harvard measures make β Tauri about 3 times brighter than ζ Tauri, and slightly less in the case of ι Aurigæ.

He found that α Lyræ (Vega) was about 4 times brighter than β Tauri. The Harvard measures make it 4·53 times brighter; and considering the roughness of Herschel's method, the above comparisons are not very discordant.

Herschel's scales of brightness and distances do not agree with modern standards. He speaks of Sirius as if it were comparable with stars like Arcturus, Capella, and Vega. He says that the light of Procyon is $\frac{16}{49}$ of the light of Sirius, but the Harvard photometric measures make Sirius 2·06 magnitudes, or 6·67 times brighter than Procyon.

For the naked eye he comes to the conclusion that "all the visible stars are probably contained within a sphere of the 12th order of distance," that is, all stars visible to the naked eye are within 12 times the distance of an average 1st magnitude star. This would give 15,625 stars to the 7th magnitude. The catalogue, he found, contained 14,144 stars to this magnitude, and this he considered a sufficiently close agreement, but concludes that the farthest stars "are more compressed than they are in the neighbourhood of the sun."

He then returns to "the construction and extent of the Milky Way." He mentions several bright spots or "patches" of light in the Galaxy. Among these the "patch under the arrow of Sagittarius, the one in Sobieski's shield, those near β, α, and γ

Cygni, and some in Cassiopeia and Perseus. He says that the breadth of the Milky Way is "very unequal. In some places it does not exceed 5°; but in several constellations it is extended from ten to fifteen." For 120°, he says, it extends "in a divided clustering stream, of which the two branches between Serpentarius and Antinous are expanded over more than 20°." He says the sun evidently lies in the plane of the Milky Way. To examine its construction by means of telescopes, he prepared a set of apertures for his different instruments which would give "space penetrating powers" from 2 to 28. He first tried these various powers on the double cluster in the "sword-handle" of Perseus, "as being probably a protuberant part of the Milky Way, in which it is situated." He found that each increase of "gaging" power increased the number of stars visible in these remarkable clusters. With the full "gaging power" of the 10-feet reflector — about 28·67—he estimated that the faintest stars extended to the 344th order of distances, while those seen with the lowest power of 2 extended from the 12th to the 24th order. This would evidently involve the hypothesis of a very elongated cone filled with stars, and with its axis pointing directly towards the earth—a very improbable arrangement. Herschel seems, however, to have been conscious of the uncertainty of this conclusion, for he says, "With regard to these gages, which, on a supposition of an equality of scattering, were looked upon as gages of distance, I have now to remark that, although a greater number of stars in the field of view is generally an indication of their greater distance from us, these gages, in fact, relate more immediately to the scattering of the stars, of which they give us a valuable information, such as will prove the different richness of the various regions of the heavens." He found that even his "20-feet telescope could not fathom the profundity of the Milky Way, and that the stars which were beyond its reach must have been farther from us than the 900th order of distances."

With the great 40-feet telescope, which, he computed, had a space penetrating power of 2300, he found that "the telescopic breadth of the Milky Way considerably exceeds the extent which in our maps is assigned to it." In a spot in the constellation Monoceros—between Procyon and Orion's "belt"—the appearance of the Galaxy led him "to suppose that there is a break or vacancy among the stars between our situation and the more remote parts of the Milky Way." He gives a number of other observations, in some of which he found the stars very numerous—over 600 stars in some fields! He concludes this paper by adding "one remarkable conclusion that may be drawn from the experiments which have been made with the gaging powers." This conclusion is, "that not only our sun, but all the stars we can see with the eye, are deeply immersed in the Milky Way, and form a component part of it." But even now this conclusion can hardly be considered as proved.

In a paper in the volume for 1818—his last paper on the subject—he gives the results of his observations and experiments "for the purpose of ascertaining the relative distances of clusters of stars, and of investigating how far the power of our telescopes may be expected to reach into space, when directed to ambiguous celestial objects." In this paper he applies the "gaging" principle to star clusters, and concluded that some of these, when examined with the 20-feet telescope, indicated distances ranging from the 144th to the 980th order of distances. Thus he estimated that Messier 11, 34, and 35 were at the 144th order, or 12 times the distance of the faintest stars visible to the naked eye; Messier 2, 3, 5, 10, 13, 15, 53, 71, 72, 74, and 92 at the 243rd order; Messier 4, 9, 19, 22, 30, 33, 56, 68, and 79 at the 344th order; Messier 62, 69, 75, and 80 at the 734th order; Messier 14 at the 900th order; Messier 77 at the 910th order; Messier 57 at the 950th order; and Messier 1 and 97 at the 980th order of distances. But the accuracy of these supposed distances is now more than doubtful.

He then speaks of "ambiguous objects," that is, nebulæ which his telescopes could not resolve into stars. Although he could completely resolve the Milky Way in some places, yet he did not consider it an ambiguous object, and he says, "We may conclude that when our gages will no longer resolve the Milky Way into stars, it is not because its nature is ambiguous, but because it is fathomless." But the idea that the Milky Way is really "fathomless" is probably incorrect. Proctor says, "Where Herschel *thought he was penetrating to the extreme limits of the sidereal system, he was in reality only analyzing more and more searchingly an aggregation in which many orders of stars were mixed up. What he failed to do was not (as he supposed) to sound the Galaxy, but to recognize as separate stars the minutest orders of orbs included within such aggregation.*"[1]

---

[1] "The Universe and the Coming Transits," p. 217. The italics are Proctor's.

With reference to the question of the resolvability of star groups as a test of distance, Proctor points out that if a star group—the components of which are equal in magnitude, and individually visible to the naked eye—be supposed to pass away into space, each separate star would become fainter and fainter, and the distances between them smaller and smaller as the group receded from the eye. Now, if the "distances between them became too small to be distinguished while the stars themselves remained visible, clearly there would result a nebulosity of appearance." "But suppose that, on the contrary, the stars of the group became invisible when the group was at such a distance that the intervals separating star from star would not be indistinguishable (if only the stars were brighter). Then clearly the group would vanish with increasing distance without ever becoming nebulous. Clearly also, if a telescope were employed to bring the retreating group into view, the same conclusion would hold good. A group which would become nebulous to the naked eye before vanishing would become so when examined under a telescope, let the telescope's power be what it might; while a group which would vanish without becoming nebulous to the naked eye would not become nebulous before vanishing under telescopic vision, whatever the telescopic power employed."[1] From this reasoning —which seems to be sound—it is obvious that the resolvability of a star group, in which the components are of equal brightness and equally distributed, depends more on the constitution of the cluster than on its distance from the earth.

---

[1] "Essays on Astronomy," pp. 340, 341.

A similar consideration is applicable to clusters containing stars of different classes of brightness. Proctor says, "Supposing a group of this kind to be passing away into space—as in the former case—the question whether it would become nebulous at any stage or stages of its progress would depend on the question whether or not the orders of stars about to disappear individually were congregated so closely that the eye could not distinguish the distances separating them."

CHAPTER XI

THE BRIGHTNESS OF THE SUN

THE sun's brightness has been variously estimated from 340,000 to 800,000 times the brightness of full moonlight, but Zöllner's estimate of 618,000 times moonlight is the one now usually accepted. The sun's brightness is so great compared with that of the brightest stars that a comparison can only be made through the medium of the moon, and even then with considerable difficulty. Various estimates have been made of the sun's brightness in terms of stellar magnitudes. Wollaston found it 25·75 magnitudes brighter than Sirius, and taking the Harvard measure of Sirius as −1·58, this would make the sun's stellar magnitude −27·33, a higher value than now generally adopted. Steinheil found −25·54, Bond −26·02, and Clark −25·47, values probably too small. Professor Young gives −26·3, Professor Newcomb −26·4, and some recent experiments by M. Fabry give the value −26·7.[1]

Instead of comparing the brightness of the sun directly with that of the brightest stars, I have recently made some calculations of the probable value of the sun's stellar magnitude by comparing its light with that of some binary stars which have the same, or a similar spectrum, and for which fairly reliable orbits have been computed.[1] The method of computation is as follows: knowing the period of revolution of the binary star in years, the semi-axis major of the orbit in seconds of arc, and the star's parallax, we can calculate the mass of the binary system in terms of the sun's mass by an extension of Kepler's third law of motion. Now, assuming the binary pair to have the same density and surface luminosity as the sun, we can find the surface of a single body equivalent in mass to the binary pair. We can thus compare the brightness of the sun with that of the binary star, the parallax and the photometric magnitude of the binary star being known. Again, calling the sun's stellar magnitude S, we can find what the sun's magnitude would be if it were removed to the distance of the binary star. Equating the two expressions thus found, we eliminate the parallax and obtain a formula for the sun's stellar magnitude in terms of the star's photometric magnitude, its period in years, and the semi-axis major of the orbit. This expression will be independent of the star's distance from the earth, and may be applied to any binary star which has a spectrum similar to that of the sun. Applying this method to the binary star α Centauri, the brighter component of which has a solar spectrum, and of which the orbit is accurately known, I find the sun's stellar magnitude $-26{\cdot}33$. The binary star ξ Ursæ Majoris, which has a spectrum of the solar type (G. Pickering), gave the value $-26{\cdot}34$, and η Cassiopeiæ (F 8 G) $-26{\cdot}65$. The mean of these values is $-26{\cdot}44$, which agrees closely with Professor Newcomb's value.

---

[1] *The Observatory*, February, 1904.

---

[1] *Monthly Notices*, R.A.S., June, 1903.

Some recent observations by Ceraski, using Venus as an intermediary, and taking the stars Polaris, Procyon, and Sirius, give a mean value of −26·59. In this volume I have adopted the value −26·5, which is probably near the truth. Possibly, however, the true value may be slightly higher, perhaps −26·7 or −26·8.

The magnitude −26·5 implies that the sun is 40,000 million times brighter than a star of zero magnitude, like α Centauri. To reduce its light to a star of this magnitude it should therefore be removed to a distance of 200,000 times (the square root of 40,000,000,000) its present distance. The parallax would then be about one second of arc, representing a light journey of about 3¼ years. To reduce the sun's light to that of a star of the 1st magnitude, like Aldebaran, it should be removed to a distance represented by a light journey of about 5 years. To reduce it to the 5th magnitude, a light journey of about 32½ years would be necessary, for the 10th magnitude about 326 years, and for the 15th magnitude 3260 years. It follows, therefore, that if any of the 15th magnitude stars, visible in large telescopes, are equal to our sun in size and brightness, they must lie at a distance of over 3000 years of light travel. There is no escape from this conclusion unless we assume an absorption of light in space, and of this there seems to be no satisfactory evidence

CHAPTER XII

THE SECULAR VARIATION OF STARS

In my book "Studies in Astronomy" (chap. xvii.) I gave some examples of stars which seem to have either increased or diminished in brightness since the earliest reliable observations of stellar magnitude were made. The following are some further interesting cases of probable change in brightness among the naked-eye stars during the last two thousand years.

Let us first consider—as before—some stars which seem to have diminished in brightness since the days of Ptolemy and Al-Sufi.

s (4) Tauri. This star lies a little north of the conspicuous pair of 4th magnitude stars *ο* and *ξ* Tauri (south-west of the Hyades). It was rated 4th magnitude by Ptolemy (or Hipparchus) and Al-Sufi, 5th magnitude by Argelander and Heis, 5–6 by Houzeau, and it was measured 5·11 with the photometer at Harvard (*ξ* being 3·75). Ptolemy rated it the same as *ο* and *ξ*, but Al-Sufi made it a little less than those stars. It forms one of a curve of four stars referred to by Al-Sufi. These are *f* (5), *s* (4), *ξ* and *ο*; *f* (5) being the most northern, and *ο* the most southern of the four. Al-Sufi rated both *f* and *s* as 4th magnitude, but at present *s* is about one magnitude fainter than *f*, and it has probably faded since Al-Sufi's time (tenth century). Its spectrum is of the Sirian type (A). The four stars referred to above were called by Ptolemy ἀποτομή, "a cutting off, a piece, segment," probably because they are apparently isolated or cut off from the rest of the constellation. Al-Sufi says that they form "a slightly curved line with the convexity turned towards the east," and that "between these stars and the Pleiades there is no star of even the sixth magnitude except a faint one [13 Tauri ?], which could only be seen with difficulty." This is quite correct, and there can be no doubt as to the four stars referred to by Al-Sufi.

π Leonis. This star, which lies about 4° southwest of Regulus, was rated 4th magnitude by Ptolemy, Al-Sufi, Tycho Brahé, Bayer, Hevelius, and Flamsteed, but it was measured 4·89 at Harvard, thus confirming modern estimates with the naked eye by Argelander, Heis, and Houzeau, who all estimated it 5th magnitude. Both Ptolemy and Al-Sufi rated it equal to ρ Leonis, but it is now nearly one magnitude fainter. The spectrum of π Leonis is of the 3rd type, a spectrum shown by many variable stars.

ι Leonis. This was rated 3rd magnitude by Ptolemy, 3–4 by Al-Sufi, 3 by Tycho Brahé and Bayer; but it was estimated 4th magnitude by Argelander, Heis, and Houzeau, and it was measured 4·03 with the Harvard photometer. Al-Sufi made it distinctly brighter than ρ (4 m.), but at present ι is slightly the fainter of the two. Its spectrum is F 5 G according to Pickering, or similar to that of Procyon.

With reference to the "extern stars" of Gemini (those outside the ancient figure), there is some difficulty in identifying Al-Sufi's 7th star. He says, "The 7th follows the three stars (85, 81, and 74 of Flamsteed), and is of small fourth magnitude; Ptolemy says fourth. Between it and the fourth, which is the northern of the three, there is less than two cubits (4° 40′) towards the south-east [this would indicate ζ Cancri]. These four stars are found between *al-gumaïsâ* [Procyon] and the 2nd bright star, which is in the head of the Posterior Twin [Pollux], nearer the bright 2nd star. The latitude of this star is also erroneous, because it follows them in their direction [that is, in a line with them] towards the north [this indicates μ Cancri], while as marked on the globe it forms a triangle with the 4th and 5th [85 and 81]. Ptolemy says that it is bright, but in reality it is of small third magnitude. There is not in this place a star of either fourth or fifth magnitude, if it is not a faint one of about the sixth magnitude." With reference to these remarks of Al-Sufi, which are very puzzling and difficult to explain, Schjellerup says, "Ce passage relatif à la 7^e etoile est tout-à-fait inintelligible; en effect, la description que nous en donne Sûfi au commencement s'applique très bien tant pour la grandeur, que pour la position, à ζ Cancri, tandis que, à la fin il parle de μ Cancri, en changeant même la grandeur." I find that Ptolemy's positions, as given by Al-Sufi, when plotted, show the 7th star in the position described by Al-Sufi, namely, forming a triangle with the 4th and 5th. This position applies fairly well to ζ Cancri, which was probably Ptolemy's star. But it does not agree at all with Al-Sufi's 7th star, which is evidently μ Cancri, as he says it follows the 4th, 5th, and 6th "in their direction," that is, nearly in a straight line with them. If Al-Sufi's estimate of "small third magnitude" was meant for μ Cancri, it must certainly have diminished in brightness, as it is now about $5\frac{1}{2}$. If, however, intended for ζ Cancri, we must come to the same conclusion, as ζ is now only slightly brighter than the 5th magnitude. Both stars have spectra of the 2nd type (F). From Al-Sufi's description of the 8th star of Cancer, it seems to be μ, and this is confirmed by Ptolemy's positions. We must therefore conclude, I think, that Ptolemy's No. 7 of the "extern stars" of Gemini was really ζ Cancri, and that Al-Sufi was mistaken in thinking that Ptolemy's position was altogether erroneous. Ptolemy's place for ζ Cancri is not quite correct, according to modern measures, but it is not so much in error as Al-Sufi thought. Near the position of Al-Sufi's "faint star of about sixth magnitude" there is one at present which was measured 6·06 at Harvard Observatory. This is DM + 19°, 1911.

With reference to Ptolemy's 21st star of the constellation Leo, Al-Sufi remarks, "Ptolemy says it is placed with the 22nd [θ], or *al-harkafa*, 'the buttocks,' to the south of the bright 20th star [δ], and is of the fifth magnitude; however, between the 20th and 22nd [δ and θ] no star is visible. It is found removed by a cubit towards the north above the bright 20th star. This indicates 72 Leonis. But Al-Sufi's identification of Ptolemy's star does not seem justified, as M. Flammarion points out in his interesting and valuable work, 'Les Etoiles,' p. 351. Flammarion identifies Ptolemy's star with Flamsteed, 71. But I cannot agree with this identification either. 71, as shown by Flammarion, lies to the *east* of a line joining δ and θ, but on plotting Ptolemy's positions, as given by Al-Sufi, I find that Ptolemy's 21st star lies to the *west* of the line joining δ and θ. I find that the nearest star in the Harvard *Durchmusterung* to the position of Ptolemy's star is DM + 17°, 2318 (6·8 m.), measured 6·86 at Harvard. This may possibly be identical with the missing star of Ptolemy (or Hipparchus). If so, it must have diminished considerably in brightness, as Ptolemy rated his star as 5th magnitude. The spectrum of this small star is of the second type (H)."

With reference to the "extern stars" of Hydra, Al-Sufi says, "The 2nd is to the north of the 15th [λ Hydræ] . . . it is situated almost in the middle between the 15th and that in the heart of the lion [Regulus]. It is of the fourth magnitude. Ptolemy says third." This description applies exactly to the star 15 Sextantis, but does not agree with Ptolemy's position. If Ptolemy's star was really 15 Sextantis, it must have diminished in brightness, as it was measured only 4·50 at Harvard. If Ptolemy's star was not identical with 15 Sextantis, it must have disappeared, or diminished greatly in brightness, as there is no star at present of even 5th magnitude in Ptolemy's position, the nearest being 22 Sextantis, which is a little south of Ptolemy's place, and was measured 5·36 at Harvard. The spectrum of 15 Sextantis is A.

β Virginis. This star was rated 3rd magnitude by Ptolemy and Al-Sufi, 3–4 by Argelander, Heis, and Houzeau; but it was measured 3·80, or only slightly above the 4th magnitude, at Harvard. The spectrum is F 8 G, or intermediate between Procyon and the sun.

η Virginis. Rated 3rd magnitude by Ptolemy and Al-Sufi, 3–4 by Argelander and Heis, and 4 by Houzeau. It was measured 4·00 at Harvard, thus confirming Houzeau's estimate. Ptolemy and Al-Sufi rated it equal to γ Virginis, but η is now one magnitude fainter than γ. η has been suspected of variable light, and has recently been found to be a spectroscopic binary. Its spectrum is of the Sirian type.

With reference to the 30th star of Centauri, which was rated 3rd magnitude by Ptolemy, Al-Sufi says he could not find any star in the place indicated by Ptolemy—about 2° following ϵ Centauri. Al-Sufi says, "Quant à la 30ᵉ, Ptolemy rapporte qu'elle est aussi située au dessous du ventre; conformément à son lien rapporté dans l'*al-madjisti*, il faut qu'il y ait entre elles moins d'une coudée de distance. Mais il n'y a ni en cet endroit ni dans ses alentours d'etoile qui puisse occuper sa place, hormis les étoiles sus-dites et connues." Here we have a star which probably disappeared, or faded considerably, between Ptolemy's time and that of Al-Sufi. Near the place indicated by Ptolemy there are some small stars. Ptolemy and Al-Sufi agree in rating θ and ι Centauri as equal (3rd magnitude), but at present θ is considerably brighter that ι.

σ Aquarii. Rated 4th magnitude by Ptolemy, 4–5 by Al-Sufi, 5–4 by Argelander, 5 by Heis and Houzeau, and measured 4·89 at Harvard. Al-Sufi estimated it as one magnitude brighter than 66 Aquarii, and so did Ptolemy, but the two stars are now almost exactly equal (5th magnitude). The spectrum is of the Sirian type (A).

83 (*h*) Aquarii. Rated 4th magnitude by Ptolemy, 4–5 by Al-Sufi, 6–5 by Argelander and Heis, 5 by

Houzeau, and measured 5·62 at Harvard. Ptolemy and Al-Sufi made it equal to ϕ Aquarii (a little north of it), but at present h is about a magnitude fainter than ϕ. The spectrum is of the Sirian type (A).

χ Aquarii. 4m. Ptolemy, 4–5 Al-Sufi, 5 Tycho Brahé and Bayer, 5–6 Argelander and Heis, 5 Houzeau, and measured 5·22 at Harvard. Here, again, Ptolemy and Al-Sufi rated χ equal to ϕ, but at present χ is considerably fainter than ϕ. The spectrum is of the 2nd type (H, Pickering).

κ Piscium. This star was rated 4th magnitude by Ptolemy and Al-Sufi, 5–4 by Argelander, 5–6 by Heis, and was measured 4·94 at Harvard. Both Ptolemy and Al-Sufi made it equal to ω Piscium, but it is now about one magnitude fainter than ω. The spectrum is of the Sirian type (A).

g (6) Orionis. Rated 4th magnitude by Ptolemy and Al-Sufi, 6 by Argelander, Heis, and Houzeau, and measured 5·18 at Harvard. Ptolemy and Al-Sufi estimated it equal to o^2 Orionis, but at present g is about a magnitude fainter that o^2. The spectrum is of the Sirian type (A).

ζ Eridani. Rated 3 by Ptolemy, 4 by Al-Sufi, 4 by Piazzi, 4–5 by Argelander, Heis, and Houzeau, and measured 4·90 at Harvard. Here we seem to have a certain diminution of light in the last 2000 years. The spectrum is of the Sirian type.

τ^2 Eridani. 4 Ptolemy, 4–5 Al-Sufi, 4 Bayer, Hevelius, and Flamsteed, 4½ Piazzi, 5–4 Argelander and Heis, 5–6 Houzeau, and measured 4·81 at Harvard, The spectrum is K, or similar to that of Arcturus.

θ Columbæ. 4 Ptolemy and Al-Sufi, 5 Houzeau, and measured 5·36 at Harvard.

φ Hydræ. Rated 4th magnitude by Ptolemy, 4–5 by Al-Sufi, 5 by Bayer, Hevelius, and Flamsteed, 6 by Houzeau, and measured 5·20 at Harvard. It was estimated 5·3 at Cordoba. Al-Sufi rated it the same as ι Hydræ (4·10 Harvard), but at present it is a magnitude fainter than that star. The spectrum is K (Pickering).

30 Hydræ. Rated 3rd magnitude by Ptolemy and Al-Sufi, 4–3 by Argelander and Heis, 4–5 by Houzeau, and measured 3·95 at Harvard. Both Ptolemy and Al-Sufi estimated it as one magnitude brighter than ε Hydræ, but it is now about half a magnitude *fainter* than that star. The spectrum is of the Sirian type.

The star δ Ursæ Majoris—the faintest star in "the Plough"—has been suspected of having diminished in brightness, as it was rated 2nd magnitude by Tycho Brahé and Bayer, or equal to the other stars in the Plough. But as it was rated 3rd magnitude by Ptolemy (or Hipparchus) and 3–4 by Al-Sufi, and its photometric magnitude is now 3·44 (Harvard), we may conclude that it has not diminished much in brightness since Ptolemy's time. Flamsteed, however, in 1700, rated it brighter than the star in "the tail," so that it may possibly vary somewhat in brightness. Flamsteed's observations of star magnitudes are, however, rather rough, and not always reliable.

Among those stars which have possibly increased in brightness, the following may be mentioned:—

α Ophiuchi. This star was rated 3rd magnitude by Ptolemy, Al-Sufi, and Tycho Brahé, 2nd by Argelander and Heis, and it was measured 2·14 with the photometer at Harvard. Al-Sufi compares it with α Herculis—which lies a little to the west of it—and says, "they are both of the third magnitude, only the star of the head of Hercules is less brilliant." (He rates α Herculis as 3–4 magnitude.) This shows that he directly compared the two stars, and found α Ophiuchi only a little brighter than α Herculis. The photometer shows that α Ophiuchi is now a full magnitude brighter than α Herculis, and indeed the great difference between the two stars is obvious at a glance. It should be stated, however, that α Herculis is irregularly variable; but as it is never brighter than the 3rd magnitude, it seems probable that α Ophiuchi has increased in brightness since Al-Sufi's time. Al-Sufi rated it the same as δ Herculis, but it is now a magnitude brighter. Its spectrum is A 5 F (Pickering).

Pollux. This star and Castor were both rated 2nd magnitude by Ptolemy and Al-Sufi, Tycho Brahé, Hevelius, and Flamsteed. Pollux was rated 1–2 by Argelander, Heis, and Houzeau, and this agrees well with its photometric mag. 1·21 (Harvard). Castor was rated 2–1 by Argelander and Heis, and 2 by Houzeau, and it was measured 1·58 at Harvard. Pigott says that Pollux was "undoubtedly brighter than Castor" in the years 1783–1785. The photometric measures at Harvard and Potsdam make Pollux about 0·4 brighter than Castor. Pollux is at present nearer to the first than the second magnitude, and it may possibly have increased in brightness since Al-Sufi's time. Its spectrum is K, or the same as that of Arcturus.

ζ Sagittæ. Rated 6th magnitude by Ptolemy, Al-Sufi, Tycho Brahé, Hevelius, and Flamsteed; but estimated as 5 by Argelander, 5–6 by Heis and

Houzeau, and measured 4·95 at Harvard. Its spectrum is of the Sirian type.

δ Sagittæ. 5m. Ptolemy, Al-Sufi, Tycho Brahé, and Bayer, 4½ Flamsteed, 4 Piazzi, Argelander, Heis, and Houzeau, and measured 3·78 at Harvard. These estimates seem to show a progressive increase of light. Al-Sufi made δ equal to β Sagittæ, but at present δ is considerably the brighter of the two.

ζ Delphini. Rated 6th magnitude by Ptolemy and Al-Sufi, 5 by Tycho Brahé, Hevelius, Flamsteed, and Piazzi, 5–4 by Argelander and Heis, 4–5 by Houzeau, and measured 4·69 at Harvard. Al-Sufi rated it equal to ι and θ Delphini, but it is now considerably brighter than either of those stars. The spectrum is of the Sirian type (A).

ω^2 Tauri. 6m. Ptolemy and Al-Sufi, 6–5 Argelander and Heis, 5 Houzeau, and measured 4·80 at Harvard. Al-Sufi rated it one magnitude less than *p* (44) Tauri, but ω^2 is now considerably brighter than *p*, and seems to have certainly increased in brightness. The estimates seem to show a progressive increase during the last 2000 years. The spectrum is of the Sirian type (A).

ε Canis Majoris. Rated 3rd magnitude by Ptolemy, Al-Sufi, Tycho Brahé, and Bayer, 3–2 by Flamsteed, 2–1 by Argelander and Heis, 2 by Houzeau, and measured 1·63 at Harvard. Both Ptolemy and Al-Sufi rated it equal to ζ Canis Majoris (3·10 Harvard), but according to the photometric measures, it is now about 1½ magnitude, or nearly four times brighter than ζ. The spectrum is of the Orion type (B 1 A, Pickering).

β Canis Minoris. 4m. Ptolemy, Al-Sufi, and Ulugh Beigh, 3 Bayer, Hevelius, Flamsteed, Argelander, Heis, and Houzeau, and measured 3·09 at Harvard. The spectrum is B 8 A (Pickering).

The Pole Star (α Ursæ Minoris) has probably increased in brightness since Al-Sufi's time (tenth century). Al-Sufi says that in his day, γ Ursæ Minoris was inferior to the Pole Star, or "at the most equal to it." He could not have seen much difference between them, as he rates them both 3rd magnitude. As γ is now just one magnitude fainter than the Pole Star (according to Argelander, Heis, and the photometric measures), Al-Sufi's remark would seem to show that the Pole Star was really about the 3rd magnitude in his time. Its photometric magnitude is 2·12 (Harvard). Al-Sufi rated β Ursæ Minoris 2nd magnitude, and at present it is only a little fainter than this estimate. He rated γ 3rd magnitude, and here again he is correct, for the Harvard measures make it 3·14. The spectrum of the Pole Star is F 8 G (Pickering), or very similar to that of the sun.

CHAPTER XIII

THE BRIGHTNESS OF STARLIGHT

It is probably a matter of common observation that on a clear moonlight night it is never absolutely dark, a certain amount of light being given by the stars. Evidently, however, this starlight is only a small fraction of moonlight. Miss Clarke, in her "System of the Stars," gives the light of all the stars down to the $9\frac{1}{2}$ magnitude about $\frac{1}{80}$ of moonlight. M. G. l'Hermite found starlight equal to $\frac{1}{10}$ of moonlight. But this latter estimate is evidently too high; the difference between a bright moonlight night and one illuminated by starlight only being very considerable.

Let us make an attempt to estimate the total amount of starlight by computing the light emitted by all the visible stars down to the faintest point of light perceptible in the largest telescopes, like those of the Yerkes and Lick observatories. The data available for this calculation are rather uncertain, but a fair approximation to the truth is perhaps possible.

To express the total amount of starlight in terms of the light of a star of, say, "zero magnitude"—like α Centauri—and thence in terms of moonlight, let us assume, as is now admitted by most authorities on the subject, that the total number of the visible stars is about 100 millions. Let us also assume that the "light ratio" is 2·512—now accepted by all astronomers—that is, that a star of zero magnitude gives 2·512 times the light of a standard star of the 1st magnitude—like Aldebaran—a star of 1st magnitude 2·512 times the light of a star of 2nd magnitude, and so on. To enable us to make this calculation, it will be necessary to estimate the number of stars in each magnitude down to the 17th magnitude, which is about the faintest visible in the great Yerkes telescope. From an examination of recent results, Professor Newcomb finds the following numbers for the stars visible to the naked eye:—

		Total.
1st Magnitude . . .	21	21
2nd ,, . . .	52	73
3rd ,, . . .	157	230
4th ,, . . .	506	736
5th ,, . . .	1740	2476
6th ,, . . .	5171	7647

The total shows all stars down to 6·4 magnitude, about the faintest visible to the naked eye.

Taking the total number to magnitude 6·0 at 7000, and allowing a factor of 3 for the total number to each magnitude below this, I find that the total number to the 15th magnitude should be about 137$\frac{3}{4}$ millions, to the 16th magnitude about 413 millions, and to the 17th magnitude about 1240 millions. Now, as the total number visible down to the 17th magnitude does not probably exceed 100 millions, it is evident that there must be a diminution in the increase, or "thinning out," of the fainter stars as we descend in the scale of magnitude. This diminution probably begins with stars of the 10th or 11th magnitude.

Assuming Professor Newcomb's figures for stars down to the 6th magnitude, and adjusting the numbers in the remaining magnitudes to suit a total of 100 millions down to the 17th magnitude, we obtain the following table :—

1. Magnitude.	2. No. of stars.	3. Equivalent No. of stars of zero mag.	4. Remarks.
Above zero	2	7	Sirius and Canopus
Zero mag.	1	1	α Centauri
0 – 0·5	5	4	Vega, Capella, Arcturus, Rigel, and Procyon
½ – 1½	13	5	
2	52	8	
3	157	10	
4	506	13	
5	1740	17	
6	5171	20	
7	15,000	24	
8	60,000	38	
9	240,000	60	
10	800,000	80	
11	2,000,000	79	
12	5,000,000	79	
13	9,000,000	56	
14	12,000,000	30	
15	17,000,000	17	
16	23,000,000	9	
17	31,000,000	5	
	Total . . .	562	

It will be noticed that the numbers in column 3 of the above table rapidly diminish for the fainter magnitudes. The fainter stars shown on photographic plates are supposed to be about the 18th magnitude, and judging from the total light of those of the 16th and 17th magnitude, we may safely assume that the combined light of all the stars of the 18th magnitude, or fainter, would be very small. If there were 100 millions of stars of the 20th magnitude—if such faint stars exist—their combined light would be only equal to that of a single star like Vega. From this it is clear that the light of all stars below the 17th magnitude may be safely neglected in making an estimate of the total amount of starlight.

In addition to the stars, there are a large number of nebulæ scattered over the surface of the heavens, but the majority of these are such faint objects that their combined light must be inconsiderable. Perrine has recently estimated that the probable number within reach of the Crossley reflector is about 500,000. Assuming for these an average magnitude of 11, we have their combined light equal to that of 20 stars of zero magnitude. Hence the total light of all the stars and nebulæ in both hemispheres would be equivalent to 582 stars of zero magnitude, like α Centauri or Vega.

Now, to find what fraction this is of moonlight, we must consider the relation between sunlight and moonlight, and the light of a star of zero magnitude. Taking the sun's stellar magnitude as − 26·5, we have sunlight equal to 39,810,000,000 stars of zero magnitude. Comparing sunlight with moonlight, Bouguer found sunlight 300,000 times the brightness of full moonlight, Euler found 374,000, Wollaston 801,072, G. P. Bond 470,980, and Zöllner 618,000. The mean of all these is 512,810; but Zöllner's estimate of 618,000 is the one now usually accepted. Assuming this value, we have—

$$\text{Moonlight} = \frac{39{,}810{,}000{,}000}{618{,}000}$$
$$= 64{,}417 \text{ stars of zero magnitude.}$$

Hence—

$$\text{Starlight} = \frac{582}{64{,}417} = \frac{1}{110} \text{ of moonlight.}$$

As this result is for the *whole* sky, we have for one hemisphere (which is all that is visible from any one place at one time)—

$$\text{Starlight} = \frac{1}{220} \text{ of moonlight.}$$

In addition to the stars and nebulæ, there is a lot of scattered nebulous light visible on photographs in various parts of the sky; but it would be very difficult to estimate what amount of light this would give.

An examination of the table given above shows that the combined light of the stars below the 6th magnitude is considerably greater than the light of those above that magnitude; so that if all the stars visible to the naked eye were extinguished, we should still have nearly the same amount of starlight.

In a recent investigation by Professor Newcomb,[1] he finds as the results of experiments that the total light of all the stars is about equal to 600 stars of zero magnitude, "with a probable error of one-fourth of the whole amount." He thinks that a positive error is more probable than a negative one, and that the number may possibly be greater than 800. He "is inclined to regard this quantity as among the most important constants of astrophysics."

---

[1] Published in 1902. My first estimate was published in *Knowledge*, August, 1901.

From some actual experiments, Mr. Gavin J. Burns finds that on an average the light of the sky is equal to that of a star of the 5th magnitude diffused over an area of half a square degree. As the whole star sphere includes an area of 41,253 square degrees, Mr. Burns' estimate would make the total amount of starlight equal to 82,506 stars of the 5th magnitude, that is, 825 stars of zero magnitude. He finds that the average luminosity of the Milky Way is only from two to three times greater than that of the rest of the sky.[1]

Probably, however, the light of the sky at night is not wholly due to starlight. Mr. Burns points out that if this were so, the luminosity of the sky should "diminish near the horizon, just in the same manner as the brightness of the stars diminishes, and for the same reason, viz. the greater absorption of light by the earth's atmosphere. As a matter of fact, the exact opposite is the case. The brightness of the sky increases perceptibly near the horizon."[2] I can fully confirm the observations of Mr. Burns. I have often noticed during my observations of variable stars that on some nights the background of the sky is comparatively dark, while on others, equally free from clouds, the whole sky seems lit up with a sort of phosphorescent glow, evidently not due to starlight. This glow seems to be variable, as on some nights it is much more conspicuous than on others.

---

[1] *Astrophysical Journal*, October, 1902.

[2] *Journal of the British Astronomical Association*, June, 1906.

CHAPTER XIV

THE NUMBER OF THE VISIBLE STARS

THE total number of stars visible in the largest telescopes and on stellar photographs is usually estimated at 100 millions. To test the probable accuracy of this estimate, I have made a number of counts of stars shown on the photographic prints given in the late Dr. Roberts's volumes of stellar photographs. These counts were made by means of a *réseau* ruled in squares on transparent celluloid. By careful measurement I find that the side of a square on the *réseau* used is 7·62 millimetres, and therefore the area of the square is 58 square millimetres. By counting the number of stars in one of these squares in various parts of the print, a good average may be obtained, and as the scale of each photograph is always given by Dr. Roberts, it is easy to compute the probable number of stars per square degree on each plate. The photographic prints show stars down to the 16th or 17th magnitude, but probably some faint stars, visible on the original plates, have been lost in the reproductions. The time of exposure of the plates varies from 1½ to 4 hours, but this seems of little consequence, for Dr. Roberts says in the preface to the second volume (1899)—

"The group of the *Pleiades* has been photographed with the 20-inch reflector during numerous intervals between 1886 and 1898, with exposures of between one minute and twelve hours. The results are that only the same faint stars and nebulosity seen upon plates which have had an exposure of one and a half hours are depicted upon those which have been exposed during ten or twelve hours.

"Several photographs of the region of the *Milky Way* in *Cygnus* (Plate 5) have been taken with the 20-inch reflector between the years 1886 and 1898, and, on comparing two of them (one with an exposure of 60^m the other with 2^h 35^m), no fainter stars could be found on one than on the other; there is no reason for suspecting that this result was due to some abnormal condition in either case, and it has been confirmed by photographs which have been taken in other areas in the sky."

In making the counts I have carefully avoided the clusters and nebulæ shown on each plate. The number of counts made varied from 15 to 50 on each print, depending on the richness of star distribution. On some prints, in which the stars were few in number, counts were made on 600 squares.

In these counts the number of stars per square degree ranged from 5460 in a rich region of the Milky Way north of η and χ Cygni down to 245 in a spot in the constellation Leo free from Milky Way light. Some portions of the Milky Way, such as those in Auriga and Monoceros, are much less rich in stars. These parts are fainter than those in Cygnus, which have a larger number of stars per square degree. This shows clearly that the fainter portions of the Milky Way owe their faintness to a smaller number of stars, and not to greater distance from the earth, as some astronomers have erroneously supposed.

The average results I have found are as follows:—

Milky Way	4137	stars per square degree
Near Milky Way . .	1782	" " "
No Milky Way . . .	408	" " "

Professor E. C. Pickering gives the following estimates of the areas covered by the Milky Way and the non-galactic regions:—

Rich Milky Way . . .	10,999	square degrees
Fainter portions . . .	4,613	" "
No Milky Way	25,641	" "

Hence we have—

10,999 × 4137 = 45,502,863
4,613 × 1782 = 8,220,366
25,641 × 408 = 10,461,528

Total . . 64,184,757

or, in round numbers, about 64 millions.

The real total may be somewhat greater, as probably some of the fainter stars, visible on the plates, are lost in the prints given in Dr. Roberts's volumes.

By the same method I have also counted the number of stars in some of the irregular clusters shown in Dr. Roberts's photographs. These clusters, I find, vary in richness from about 12,000 stars per square degree down to 2520, the average of 12 clusters being 5752 stars per square degree, or only a little more than the richest parts of the Milky Way. The globular clusters are, of course, much richer than this. Professor and Mrs. Bailey's counts of stars in the great globular cluster ω Centauri give about 25,000 stars to the square degree. This would give for the whole heavens, if equally rich, over 1000 millions of stars. But as ω Centauri is, of course, *unusually* rich in stars, we may conclude with confidence that the actual number of the *visible* stars is far short of 1000 millions. An estimate of 100 millions is probably a maximum.

CHAPTER XV

STELLAR BRIGHTNESS AND DENSITY

SEVERAL attempts have been made to determine the brightness of the sun in terms of the brightest stars. This is a matter of no small difficulty, as the sun is so enormously brighter than any of the stars, and cannot, therefore, be *directly* compared with them. By indirect methods, however, a close approximation has been made to the truth, and the best recent determinations makes the sun's brightness between 26 and 27 magnitudes brighter than the zero of stellar magnitudes. This zero is fairly represented by the brightness of the star α Centauri; and Vega and Arcturus are only slightly below this zero. The number −26·5 may be taken as the mean of the best estimates of the sun's brightness. This implies that the sun is 40,000 million times brighter than α Centauri. Now, as light varies inversely as the square of the distance, it follows that the square root of this number, or 20,000, will represent the distance to which the sun should be removed in order to reduce its brightness to that of α Centauri. That is, if the sun were removed to 20,000 times its present distance, its light would be reduced to that of a star of zero magnitude, like α Centauri. As the distance of some of the stars has been determined with considerable approach to accuracy, we can compare the total light emitted by them with that which the sun emits. Let us consider those stars of which the distance has been most accurately determined, and see how their brightness compares with that of the sun.

For α Centauri the parallax has been well determined, and is about 0·75 of a second of arc. That is the angle which the distance between the sun and earth would subtend at the distance of the star. Placed at the distance indicated by this parallax—the largest yet found for any star—the sun would, I find, be reduced in brightness to a star of 0·69 magnitude, or a little fainter than the bright star Procyon. This implies that α Centauri is about 1·79 times brighter than the sun. It is a well-known double and binary star, the brighter component being 0·36 magnitude, according to the Harvard photometric measures, and the fainter 1·61 magnitude. The brighter component is therefore only a little brighter than the sun would be if placed at the same distance from the earth, and as its mass has been shown to be equal to the sun's mass, and its spectrum the same, we may consider it as about a duplicate of our sun. A slight increase in the assumed value of the sun's stellar magnitude would make them exactly equal in light. On the other hand, the fainter component of the pair has only 0·43 of the sun's light, and as its mass is also equal to the sun's mass, it is either of smaller size—that is, more condensed—or has a smaller luminosity of surface. Its spectrum agrees with this conclusion.

The bright star Sirius has a parallax of about 0·37 second. This, combined with its magnitude of −1·58, or 1·58 magnitudes above the zero of stellar magnitudes, makes it about 33 times brighter than the sun—that is, the light of Sirius is equal to that of 33 suns.

The bright star Procyon, with a parallax of 0·325 second, is about 6½ times brighter than the sun; and Aldebaran, with a parallax of 0·107 second, has a brightness equal to that of 35 suns. Capella seems to have the light of about 128 suns, although its mass is only about 17 times the sun's mass. As its spectrum is almost identical with the solar spectrum, we have here an anomaly which has not yet been satisfactorily explained.

If any reliance can be placed on the small parallax found for some of the bright stars, they must be suns of enormous size or great brilliancy of surface. Thus I find that Arcturus is no less than 1486 times brighter than the sun, Antares 787 times, α Gruis 648 times, Regulus 642 times, Achernar 331, β Centauri 227, and α Crucis 166 times.

Some of the stars are, however, much fainter than our sun. For the small star Lalande 21,185 (magnitude 7·60), Mr. H. N. Russell has recently found a parallax of 0·344 second. This indicates that the sun is about 100 times brighter than the star, and suggests that this star is a comparatively small body. The character of its spectrum has not been determined, but if we assume that it has the same density and surface brilliancy as the sun, the above result would imply that its diameter is only one-tenth of the sun's diameter, or about 86,000 miles—or about the diameter of the planet Jupiter. The small star known as Cordova Zone V. 243, which has the large proper motion of 8·7 second per annum (the largest known), has been found to have a parallax of 0·312 second. This gives a brightness of only 0·004 of the sun's brightness, and would indicate a still smaller body. But in this case also the spectrum is unknown.

The brightness of a star, or its so-called "magnitude," depends on three factors—(1) its distance from the earth; (2) its diameter; and (3) its intrinsic brilliancy, or the actual luminosity of its surface per unit of area. The first of these factors—the distance from the earth—has in a few cases been determined with considerable accuracy, either by micrometrical measures of comparison stars, or from spectroscopical observations of binary stars. The second factor—the diameter of the star—is more difficult to determine, and its measurement has not been satisfactorily accomplished, except perhaps in some variables of the Algol type. An approximation to its probable value may, however, be arrived at from other considerations. The third factor—the luminosity of the star's surface—may be inferred, to some extent at least, from the character of the star's spectrum. This luminosity of surface, or intrinsic brightness[1]—as it is sometimes called—probably depends on the mass and density of the star. Two stars may have the same mass—that is, quantity of matter—but one may have a large volume and small density, and the other a small volume and greater density. The difference is probably due to temperature. And then the question arises, which of the two stars will be apparently the brighter? We know that heat causes a mass of gas to expand, and the greater the heat, the greater the expansion. And with a given mass, the greater the expansion, the smaller the density will be. This is evident. Hence a star with a high temperature would have a large volume and small density. And it seems probable that, the higher the temperature the greater will be the luminosity of its surface. From this it would follow that a star with a high temperature would have a large volume and light-giving surface, and also a greater luminosity of surface, and both cases would thus combine to increase its apparent brilliancy. It is probable, however, that this would not apply to the nebulæ, but only to bodies, like the stars, which have consolidated to a certain extent.

---

[1] This term was used by Sir William Herschel. See p. 163.

It is now admitted by many eminent astronomers that stars with the "Orion type" of spectrum (B, Pickering), such as Bellatrix (γ Orionis), δ, ϵ, and ζ Orionis, are—with the possible exception of the "Wolf-Rayet stars"—the most luminous among the brighter stars. Next to these come stars with the Sirian type of spectrum (A, Pickering), followed probably in decreasing order of luminosity by stars of the second or solar type, and then by the third, and perhaps fourth type stars. The "Algol variable" U Ophiuchi has a spectrum of the "Orion type," and some of the other "Algols," such as Algol, λ Tauri, and V Puppis, show a spectrum intermediate between the B and A type. These will be considered further on.

The probably great luminosity of stars with the "Orion type" of spectrum is shown by the fact that Sir David Gill finds that the parallax of Rigel is almost certainly not more than the hundredth of a second of arc, and yet it is one of the brightest stars in the sky—seventh in order of brightness according to the Harvard photometric measures. At the vast distance indicated by this minute parallax, our sun would be reduced to a star of about the 10th magnitude, and would therefore be invisible even with a binocular field-glass. Rigel is therefore about 7800 times brighter than the sun would be if removed to the same distance from the earth. It has a small companion of the 8th magnitude, but as the pair have not yet been proved to be a binary (although the companion, which is double, probably is), we cannot determine its mass. But it is evident that it must be a sun of enormous size and great luminosity of surface to shine as brightly as it does at such a vast distance from the earth—over 300 years' journey for light. Comparing it with Sirius, whose mass and distance have been well determined, I find that the mass of Rigel is probably about 20,000 times the sun's mass.

The great brilliancy of stars with the Sirian type of spectrum is shown by Sirius itself, the distance of which has now been satisfactorily determined. From its apparent brightness and parallax, I find, as already stated, that Sirius is about 33 times brighter than the sun would be at the same distance. From the orbit of the satellite, Dr. See finds its mass to be 2·36 times the sun's mass, and from this it follows that its real brightness is about 18 times greater than that of the sun in proportion to its mass. Its spectrum shows that it is probably at a higher temperature than our sun.[1] Its volume is therefore probably larger, and, as Dr. See says, there "is some reason to suppose that *Sirius* is very much expanded, more nearly resembling a nebula than the sun." But here the question arises, is its greater brilliancy due to its larger volume, and smaller density, or to its greater surface luminosity, or to both cases combined? As it is 33 times brighter than the sun, a diameter equal to the square root of 33, or 5·74 times the sun's diameter, would give the necessary brightness (if the surface luminosity of Sirius and the sun were the same). Assuming this for a moment, I find that with a diameter of 5·74 times the sun's diameter—or about 5 millions of miles—its volume would be about 189 times greater than the sun's volume, and its density only $\frac{1}{80}$ of the sun's density. Now, as the sun's density is 1·40 (water = 1), we have density of Sirius—on the above assumption of equal surface luminosity—only 0·017 that of water. This seems improbable, judging from the known case of Algol, which has a much higher density than this. We may therefore conclude, I think, that the great brilliancy of Sirius is probably due to both causes combined, namely, a somewhat larger volume and a greater luminosity of surface than the sun. If we assume that its density is the same as that of Algol, say 0·34, we have the diameter of Sirius about 1,860,000 miles, and its surface luminosity about 7 times that of the sun.

---

[1] Hale, Huggins, and Schuster agree in the opinion that Sirian stars are hotter than solar stars.

For δ Equulei, a binary star with the very short period of 5·7 years, Professor Hussey finds from spectroscopic observations a parallax of 0·071 second and a combined mass of 1·89 times the sun's mass. He says, "The components of the pair are slightly unequal in brightness, and perhaps also in mass. One may be as massive as the sun, but it cannot much exceed it."[1] The parallax found by Hussey would, I find, reduce the sun to a star of about 5·81 magnitude, and as the photometric magnitude of δ Equulei is 4·61, we have the star 1·20 magnitudes, or 3 times brighter than the sun. Assuming that the masses of the components are 1·00 and 0·89 (as suggested by Hussey), I find that if the density and surface luminosity of each were equal to that of the sun, the combined light of the two components would be 1·9247, or nearly twice the sun's light. The star's spectrum is of the type F, indicating probably a somewhat brighter star than ours. This difference in the results found above is not inconsistent with the parallax found by Hussey. Indeed, it seems probable that his result cannot be far from the truth. A comparison with Procyon is also, I find, confirmatory of Hussey's result.

---

[1] *Astrophysical Journal*, June, 1903.

For the famous binary star γ Virginis, which has also a spectrum of the F type, Lewis finds a period of 182 years. Numerous orbits have been computed for this remarkable pair, but the orbit found by Lewis seems to be the best. From meridian observations Lewis finds that the components are nearly equal in mass, as they are nearly so in light. Assuming a parallax of 0·10 second—which seems a very probable value—Lewis finds that each component has about nine-tenths of the sun's mass. With this parallax the sun would be reduced to a star of about the 5th magnitude. The photometric magnitude of the star is 2·91. The magnitude of each component would therefore be 3·66. From these data it follows that the light of γ Virginis is about 7 times the light of the sun. If of the same surface luminosity and density as the sun, the combined light should, I find, be only 1·86 times the sun's light, or only a little more than one-fourth of what it actually is. This shows that the surface luminosity of γ Virginis is considerably greater than that of the sun. If the components had the same surface luminosity as our sun, let us see what their density would be. Each has 3·5 times the sun's light, and the diameter of each would therefore be the square root of 3·5, or 1·87 times the sun's diameter; and with a mass of 0·9 times the sun's mass, the density would be only 0·2 (water = 1). This seems improbable, as it is so much less than the sun's density (1·4). If each had, say, 1·2 times the sun's diameter, we should have a total of $(1{\cdot}2)^2 \times 2 = 2{\cdot}88$, as due to the increased surface. This would give a factor of about 2·4 for the surface luminosity, and the density would then be about 0·73, which seems a probable value.

In these cases of δ Equulei and γ Virginis, we see that the factor of surface luminosity is probably less than in the case of Sirius, and suggests that Sirius is a brighter body, as its spectrum would seem to indicate.

Let us now consider the case of the bright star Procyon, which has a spectrum F 5 G, or intermediate in character between that of γ Virginis and the sun. Its parallax is about 0·325 second, and the mass of the system is therefore, from Dr. See's orbit of the satellite, 3·627 times the sun's mass, that of the bright star being about 3 times the mass of the sun. At the distance indicated by the parallax the sun would, I find, be reduced to a star of 2·51 magnitude, and as the photometric magnitude of Procyon is 0·48, we have the star 2·03 magnitudes, or 6·487 times brighter than the sun. As, however, the mass of Procyon is 3 times the sun's mass, the star should be—if of the same density and surface luminosity as the sun — only 2·08 times brighter than the sun. Hence it follows that Procyon is really $\frac{6{\cdot}487}{2{\cdot}08}$, or 3·1 times brighter than our sun in proportion to its mass. This may be due either to a proportionally larger size, and therefore less density than the sun, or to a greater luminosity of surface. Probably both causes combine to produce the increased brightness, and the result seems to agree well with the star's spectrum, which indicates a slightly more luminous sun than ours.

The binary star 70 Ophiuchi has a spectrum of the second type (K, Pickering), probably indicating a fainter sun than ours. An orbit computed by Dr. See, combined with a parallax of 0·16 second found by Schur, gives a combined mass of 2·94 times the mass of the sun. This parallax would reduce the sun to a star of about 4·05 magnitude, and as the photometric magnitude of 70 Ophiuchi is 4·07, the star is about equal to the sun in brightness. But as the mass is 2·94 times greater, the star should be—if exactly comparable with the sun—about twice as bright as it actually is. Hence it would follow that the surface luminosity is less than that of the sun, and the spectrum indicates that such is probably the case.

Let us now consider the case of the "Algol variables." For Algol itself Vogel found from spectroscopical observations the diameter of the bright star to be 1,074,100 miles, with a mass of four-ninths of the sun's mass, and for the "dark" companion a diameter of 840,600 miles, and a mass of two-ninths of the solar mass. This result was obtained on the assumption that both components are of equal density—about one-third that of water. But that a "dark" body of such large size should have the same density as a very bright body like Algol seems highly improbable. The density of the planet Jupiter, which has probably some inherent light of its own, is about 1·30, and that of Saturn about 0·72. We should therefore expect that a large body like the companion of Algol would have a considerable amount of inherent light or surface luminosity. Let us see what brightness it *could* have without sensibly affecting the observed light variation of Algol. That is, what is the maximum brightness which the companion might have without producing a secondary minimum when hidden behind the disc of the bright star? Chandler finds for Algol a parallax of 0·07 second. The sun, if removed to the distance indicated by this small parallax, would, I find, be reduced to the light of a star of 5·84 magnitude, and the photometric magnitude of Algol being 2·31, it would be 3·53 magnitudes, or nearly 26 times, brighter than the sun. Let us assume that the companion has this magnitude of 5·84. Then when in the course of its orbital revolution round Algol it is hidden behind the bright star, the normal light of Algol would be reduced by its 27th part. This means that the light of Algol would be diminished by about 0·04 magnitude, or from 2·31 to 2·35, a difference which would not be perceptible to the naked eye, and could hardly be detected with certainty by even the most delicate photometer.

The spectrum of Algol is, according to Pickering, B 8 A, that of Sirius being A. It is therefore nearer to Sirius in character than the stars of the "Orion type" (B). Comparing the two stars, and assuming the surface luminosity to be the same, I find a parallax of 0·11 second for Algol. This would reduce the sun to a star of 4·84 magnitude, and if we suppose the companion to Algol to have this brightness, then Algol would be over 10 times brighter than the companion, and when the latter was hidden behind the bright star, the light of Algol would be reduced from about 2·31 to 2·41, and even this difference could hardly be determined with certainty. It is therefore quite possible that the companion to Algol may shine as a star of the 5th or 6th magnitude. It is much too close to Algol to be seen with the largest telescopes, and even the spectroscope would show no trace of its existence.[1] Observations by Plassmann and others seem to show some fluctuations in the light of Algol during its so-called "normal" period, but to a greater extent than indicated by the above computations. It would seem probable, therefore, that the companion has some inherent light of its own, and is not quite a "dark body." Assuming a parallax of 0·07 second, I find that the surface luminosity of Algol itself would be about 17 times greater than that of the sun.

In the Algol system the components are separated by a distance of over two millions of miles (between their *surfaces*), but in some of the "Algol variables" the components are supposed to revolve in contact, or nearly so. They have also both the components bright. Examples of this type of variation are β Lyræ, U Pegasi, V Puppis, X Carinæ, and RR Centauri. The characteristics of the light fluctuations in these cases are, according to Dr. A. W. Roberts,[1] as follows: (1) "continuous variation, indicating that the component stars are in contact," and (2) two maxima and two minima, showing that the components are both bright bodies. The variation of β Lyræ is well known. It is not usually considered as an Algol variable, but it now seems probable that it should be included in that type. Myers finds that β Lyræ probably consists of two ellipsoidal components revolving nearly in contact, the mass of the larger component being 21 times the mass of the sun, and that of the smaller 9½ times the sun's mass. He thinks the mean density of the system "is comparable with atmospheric density;" that is, that they are "in a nebulous condition." If this conclusion is correct, the diameter of the bodies composing the system of β Lyræ must be enormous. Taking the density of atmospheric air as 814 times less than water, I find that the larger component would have a diameter of about 25 millions of miles, and the smaller about 19 millions. The parallax of β Lyræ has not been ascertained, but supposing it to be about one-hundredth of a second of arc, the sun would be reduced to a star of about the 10th magnitude. The maximum brightness of β Lyræ is about 3·5. It would therefore be—with the assumed parallax—6½ magnitudes, or about 400 times brighter than the sun. From the diameter found above, the combined surfaces of the two components would be 1332 times the sun's surface. Hence the intrinsic luminosity of their surface would be less than one-third of that of the sun. This agrees with Homer Lane's law, by which a gaseous mass gains in heat as it consolidates, and β Lyræ is probably in a very early stage of stellar evolution. If the parallax is larger than that assumed above, the surface luminosity would be still smaller.

---

[1] *Astrophysical Journal*, May, 1904. Paper on δ Orionis, by J. Hartman.

---

[1] *Monthly Notices*, R.A.S., June, 1903.

Another remarkable star is the southern "Algol variable" V Puppis (Lacaille 3105). Both components are bright bodies. The spectrum of the brighter component is, according to Pickering, of the "Orion type" B 1 A, and that of the fainter B 3 A. The period of light variation is 1·454 days. The spectroscopic observations show that the relative velocity is about 380 miles a second. The combined mass of the system is therefore about 70 times the sun's mass. As the star is variable, the plane of the orbit must necessarily pass through the earth, and the accuracy of this result for the mass is therefore certain. This enormous mass and the star's magnitude—about 4·50—shows that it is probably at an enormous distance from the earth. As it lies in or near the Milky Way, it may possibly be one of the larger stars of the Galaxy. Dr. A. W. Roberts finds that the components "revolve round one another in *actual* contact." The star is thus a very remarkable and interesting object. Its mass is very large. Its density is probably small, and the intrinsic luminosity of its surface very high. Its distance from the earth is very great. Its orbital velocity is very rapid, and the variation of light is small and very regular. It is, in fact, one of the most remarkable objects in the heavens.

CHAPTER XVI

THE SIZE OF STELLAR SYSTEMS

AMONG the numerous binary or revolving double stars now known to exist in the heavens, there are about 50 for which satisfactory orbits have been computed. That is, the *apparent* dimensions of the real orbit are accurately known. Unless, however, we can find the star's distance from the earth, we cannot calculate the *real* dimensions of the stellar system. For some of these binary stars, however, a satisfactory "parallax" has been found, and for these we can compute the real size of the system. Let us consider those binary stars which have the most trustworthy parallaxes.

α Centauri. For this fine binary star—the nearest star to the earth—a good orbit has been computed by Dr. See. This gives a period of 81·1 years, an apparent semi-axis major of 17·7 seconds, and an eccentricity of 0·528. A satisfactory parallax of 0·75 second has been found by Sir David Gill. We have thus all the necessary data for computing the real dimensions of this interesting system. Calling the apparent semi-axis major a, the parallax p, and s the real length of the semi-axis major in terms of the sun's mean distance from the earth, taken as unity, we have $s = \frac{a}{p} = 23{\cdot}6$, or a little more than the distance of Uranus from the sun. To find the greatest and least distances between the components, let the eccentricity $= e$. Then the maximum distance $= s(1 + e)$, and the minimum distance $= s(1 - e)$. This gives for α Centauri the maximum distance = 36·06, and the minimum distance = 11·14. The components were at their minimum distance in the year 1875, that is, the minimum distance in the *real* orbit; the minimum distance in the *apparent* orbit occurred in 1877. The maximum distance in the real orbit will take place in the year 1918, but in the *apparent* orbit this occurred in 1897. Calling the brighter component A, and the fainter B, the photometric measures at Harvard Observatory make the "magnitude" of A 0·36, and that of B 1·61. Now, knowing the distance between the components, and the star's distance from the earth, we can easily calculate the apparent brightness of each component as seen from the other. Making the necessary calculations, I find that the brightness of B, as seen from A, will vary from −17·8 to −20·35 magnitudes, and that of A, as seen from B, from −19 to −21·63. As the sun's stellar magnitude is about −26·5, it follows that the components of α Centauri, as seen from each other, will shine as small suns. It is sometimes stated that each component would only appear as a very bright star, as seen from the other. This is to a certain extent true, as the mean brightness would be about the same as the brightness of the sun as seen from Neptune. But still they would be incomparably brighter than any of the fixed stars. The light of B, as seen from A, would, even at its minimum, be about 200 times the light of full moonlight on the earth. The parallax combined with the period and mean distance between the components gives a combined mass of just twice the sun's mass, and as measures have shown that the components are practically equal in mass, each of them has a mass equal to that of our sun. The spectrum of the brighter component is similar to that of the sun (G), and it is probably almost a duplicate of our sun. The spectrum of the fainter component is K 5 M, or between the second and third types of stellar spectra, and as it is 1·25 magnitude, or over 3 times fainter than the primary star, its light is much less in proportion to its mass. It is therefore probably in a different stage of its evolutionary history, although both components are in all probability of the same *chronological* age.

Sirius. The parallax of this brilliant star—the brightest star in the heavens—has also been satisfactorily determined by Dr. Gill, who finds 0·37 second, or a distance of 8·8 years' journey for light. A new orbit for the satellite has recently been computed by Dr. Doberck, who finds a period of 49·49 years, with $a = 7·513$ seconds and $e = 0·5871$. From these data the combined mass of the system is 3·415 times the sun's mass, and the mean distance between the components 20·3 times the sun's mean distance from the earth. Owing, however, to the large eccentricity of the orbit, this distance will vary from 8·4 to 32·2. Taking the brightness of the satellite as 10th magnitude, I find that its brightness, as seen from Sirius, will vary from -11 to -14 magnitude, its mean brightness being therefore about the same as that of full moonlight on the earth. Sirius seen from the satellite will, I find, vary in brightness from -22 to $-25·7$, or from $\frac{1}{30}$ of sunlight on earth to $\frac{1}{2}$

sunlight. Although Sirius is a much brighter sun than ours, its great distance from the satellite will reduce its brightness considerably.

70 Ophiuchi. Dr. See finds a period of 88·4 years, with $a = 4{\cdot}55$ seconds and $e = 0{\cdot}500$. A parallax of 0·16 second was found by Schur. With these data the mean distance is 28·4, and the greatest and least distances 42·6 and 14·2 respectively. The magnitudes of the components being about 4 and 6, I find that B, seen from A, would vary in brightness from −16·4 to −18·8 magnitude; and A, seen from B, from −18·4 to −20·8. The mass of the system, from the above data, would be nearly 3 times the mass of the sun. The spectrum is K, and the intrinsic luminosity seems to be small in proportion to the mass.

δ Equulei. Period 5·7 years, $a = 0{\cdot}28$ second, and $e = 0{\cdot}46$ (Hussey). From spectroscopic measures Hussey finds a parallax of 0·071 second. From these data the mean distance between the components is 4 times the sun's mean distance from the earth, the distance varying from 2·16 to 5·84. Taking the magnitudes as 5 and 5·5, I find that the brightness of B, as seen from A, would vary from −23·0 to −25·1, and that of A, seen from B, from −23·5 to −25·6. Each component would therefore appear as a small sun as seen from the other. The sun placed at the distance indicated by the above parallax would shine as a star of about 5·8 magnitude, the combined light of the components of δ Equulei being 4·61. Hussey finds the mass of the system to be 1·89 times the sun's mass. The spectrum is F, and the intrinsic luminosity somewhat higher than that of our sun. The star is also a spectroscopic binary, so it is really a triple star.

γ Virginis. Belopolsky found by the spectroscopic method a parallax of 0·051 second. Dr. See finds a period of 194 years, with $a = 3{\cdot}99$ seconds and $e = 0{\cdot}897$. This would make the mean distance between the components 78 times the sun's mean distance from the earth, but owing to the great eccentricity of the orbit, the distance varies from 8 to 148. The components are nearly equal in brightness. Taking the magnitude of each at 3·65, I find that the brightness of each component as seen from the other will vary from −18·53 to −24·85, or over 6 magnitudes. The mass of the system, according to Belopolsky, is 15 times the sun's mass. The spectrum is F, and the intrinsic brightness considerably greater than that of our sun.

With reference to the "spectroscopic binaries," most of them seem to be constructed on a much smaller scale than the visual binary systems. As the spectroscopic measures give the actual orbital velocities in miles, the real dimensions of the system can be calculated, although their distance from the earth remains unknown. Some of these remarkable systems are comparatively quite small. Thus in β Aurigæ the distance between the components is about 8 millions of miles. In the variable star Algol the distance between the components from centre to centre is about $3\frac{1}{4}$ millions of miles, and in ζ Geminorum the mean distance is only a little over one million of miles. But in other cases the distance is greater, and probably there are stellar systems of all dimensions from a few hundred thousand miles to many millions.

CHAPTER XVII

THE SATELLITE OF SIRIUS

THE brilliant star Sirius—the brightest in the heavens—has a faint companion of about the 10th magnitude, that is, so faint that it would be quite invisible in a binocular field-glass even if it shone alone on a dark sky. But placed as it is, close to a brilliant star like Sirius, it requires a large telescope to see it at all. Since its discovery by Alvan Clark—the famous American optician—in 1862, it has been carefully observed and measured, and the numerous measures of position now accumulated show that it is revolving round the bright star in a period of about 50 years. From its orbit, and the distance of Sirius from the earth found by Sir David Gill, it has been computed that, faint as it is, the satellite has a mass equal to that of our sun. I find that if the sun were placed at the distance of Sirius, its light would be reduced to that of a star only a little below the 2nd magnitude. In other words, the sun is about $7\frac{1}{2}$ magnitudes brighter than the small star. This means that the light emitted by the sun is a thousand times that emitted by the faint companion of Sirius. This fact is so anomalous that it seems to deserve more consideration than it has hitherto received.

The faintness of this small star must be due either to its small size—that is, small volume—or to its small luminosity of surface. I will proceed to show that a small volume is inadmissible, and that a small luminosity of surface is the only tenable hypothesis. I have shown elsewhere that the satellite of Sirius could not possibly shine merely by light reflected from the bright star.[1] For in that case it would be absolutely invisible in the largest telescopes hitherto constructed.

If its faintness were merely due to its small size, its surface luminosity being equal to that of our sun, the sun's diameter should be the square root of 1000, or $31\frac{1}{2}$ times the diameter of the faint star, in order to produce the observed difference of light. But on this hypothesis the sun would have a volume 31,500 times the volume of the star, and, as the density of a body is inversely proportional to its volume, we should have the density of the Sirian satellite over 44,000 times that of water (the sun's density being 1·4). This is, of course, entirely out of the question, and the result shows at once that the luminosity of the satellite's surface cannot possibly be comparable with that of the sun. Its surface must be enormously less luminous than the sun's surface.

Let us consider what luminosity of surface the satellite could have consistently with its having a comparatively low density. As it shines by inherent light, it must be very hot, and hence its density cannot be very high. If the earth were intensely heated so as to become self-luminous, it would expand in volume, and therefore diminish in density. Suppose it expanded to twice its present diameter, then its volume would be increased 8 times, and its density would diminish from 5·53—its present value—to 0·69, or about the density of the planet Saturn. If we assume that the satellite of Sirius has a surface luminosity of, say, 0·01 of the sun's luminosity—or about the same as that of the binary companion of 40 (o_2) Eridani—we have surface of sun 10 times the surface of the star. In this case the sun would have 31·63 times the volume, and the density of the star would be 44·28 (water = 1), a value which also seems inadmissible, as there is no known substance with nearly so high a density. Further, if it could possibly have so high a density, it would certainly be a dark body, and not self-luminous. Assuming a luminosity of 0·002 of the sun's luminosity, the density would be 3·96, which seems an improbably high value for a self-luminous body.

---

[1] "Studies in Astronomy," p. 113.

If we assume a luminosity of 0·0015, the density of the satellite becomes 2·57, a value which seems to be still too high. A luminosity of 0·001 would of course make the satellite of the same volume and density as the sun, but if it had the same density as the sun, there seems to be no reason why its luminosity should be so small.

We may therefore conclude, I think, with great probability, and almost certainty, that the luminosity of the Sirian satellite does not exceed 0·0015 of that of the sun. But even this small luminosity would give a considerable amount of light. Assuming that sunlight is about 600,000 times moonlight, we have the luminosity of the satellite equal to 900 times that of the moon's surface. This is, however, very small for a body shining by inherent light, and suggests that the satellite has cooled down considerably, and that it is probably far advanced on the road to the total extinction of its light. It is unfortunate that its spectrum cannot be observed, as it should be a most interesting one. But perhaps this may be possible in the future with a gigantic reflecting telescope. It is, of course, possible that the satellite may be a large globe of very low density and small luminosity, like the gaseous nebulæ. In that case we should expect to find a spectrum of the nebular type, that is, one with bright lines on a dark ground. But it is said to have a reddish colour, which points rather to its being a cooled-down sun, in which case it would probably show a banded spectrum of the third or fourth type. From these considerations it seems that the satellite must have either a comparatively high density or else a low one, and its spectrum would probably decide the question.

In the case of the companion to Procyon, which is a fainter star, and has a smaller mass than the Sirian satellite, Mr. Lewis noted in March and April, 1898, that "the appearance of the companion to *Procyon* was not so like a star as that of Sirius, and that while the wire of the micrometer totally eclipsed the companion of *Sirius*, the companion of *Procyon* was seen on both sides of the wire."[1] This is very suggestive, and seems to show that the faint satellite of Procyon is probably a small gaseous nebula. Its colour is said to be "purplish," which perhaps points to the same conclusion.

---

[1] *Monthly Notices*, R.A.S., April, 1898.

CHAPTER XVIII

"HOLES IN THE HEAVENS"

"Sed patet immiani et vasto respectat hiatu."[1]

THE Milky Way is not of uniform brightness. There are many dark spots in it which seem to be openings or holes through that wonderful zone of stars. These dark spots, or "coal sacks," as they are also called, seem to have been first noticed by Pinzon in 1499. These were also described by Lacaille in 1763, and Sir John Herschel mentions several of these curious spots in his "Cape Observations."

The most remarkable of these spots is the well-known "coal sack" near the Southern Cross. It is of a roughly oval or "pear-shaped" form, about 8° in length by 5° in width, and forms a conspicuous object in the sky of the southern hemisphere. It is completely surrounded by the nebulous light of the Milky Way, which is here rather bright. The bright stars α and β Crucis—the brightest stars of the Southern Cross—nearly touch its north-western border, and the star θ Muscæ lies close to its south-eastern edge. It contains only one small star visible to the naked eye within its boundaries. With reference to its northern border, Sir John Herschel says, "The transition from rich Milky Way to almost complete darkness is here very sudden." It is, however, by no means devoid of faint stars. On a photograph taken by Mr. H. C. Russell at the Sydney Observatory in 1891, numerous small stars are visible, but there are several spots which seem to be completely void of stars and absolutely black. One of these remarkable holes is near β Crucis, and another near α Crucis.

---

[1] Lucretius, "De Rerum Natura," v. 373.

There are other remarkable "coal sacks" in the Milky Way. A long, narrow dark spot runs from α Centauri for several degrees towards the northeast. There are several in Scorpio; one of larger size between β and ε Cygni, and one south of α Cygni.

Examined with a telescope, the Milky Way shows many examples of small "coal sacks," and some may be seen on very clear nights with even a good binocular field-glass. One night, when Sir William Herschel was examining a part of the Milky Way closely east of the globular cluster 80 Messier, which lies between ν and σ Scorpii, he suddenly exclaimed to his sister, the famous Caroline Herschel, "Hier ist wahrhaftig ein Loch im Himmel" ("Here, truly, is a hole in the heavens"). It was an absolutely black spot about 4° in width, perfectly free from any stars, and especially remarkable owing to its proximity to one of the richest globular clusters in the heavens.

Closely south of Herschel's dark "hole" just mentioned, Professor Barnard has photographed a great nebulous surrounding the stars ρ Ophiuchi and 22 Scorpii.[1] This photograph shows several dark lanes in what seems to be at least a comparatively thin sheet of stars, and this distinguished astronomer thinks "it is certain that these stars are at the same distance as the nebula, for they form part of it." With reference to the Milky Way in general, he thinks that the stars composing it are "comparatively very small bodies, and that they consequently differ vastly, in point of size at least, from the ordinary stars of the sky." If this be so—and the evidence seems to point in this direction—it would follow that their distance from the earth may not be so great as their faintness would lead us to imagine. In his "Cape Observations" Sir John Herschel gives a list of 49 spots in the southern hemisphere "totally devoid of any perceptible star." But probably photography will reveal some faint ones.

---

[1] The rings round the brighter stars in the photograph are due to a photographic effect, and do not exist in the sky.

Close to the star θ Ophiuchi is a "dark chasm which passes south and west of that star," and there are other dark spots or holes in the vicinity clearly visible on a photograph taken by Professor Barnard at the Lick Observatory. Another small black spot was observed by Barnard a little north-west of the star γ Sagittarii. This seems to have been previously seen by Trouvelot, who says, "C'est comme un sac à charbon en miniature, ou une ouverture de Voie lactée à travers laquelle la vue pénètre au dela de ce grand assemblage d'étoiles.'

A little south-east of α Cephei, a photograph by Barnard shows a ring of nebulous light with a comparatively dark interior, at least the stratum of stars filling the ring seems pierced by several holes.

The "key-hole" opening in the great nebula surrounding the variable star η Argûs is a remarkable feature of that wonderful nebula. A little south of this hole there is a "kidney bean" shaped opening shown on Sir John Herschel's drawing in the "Cape Observations." This opening is visible on a photograph taken by Sir David Gill in March, 1892. The photograph confirms the accuracy of the drawing, and shows that the opening is in all probability a real hole through the surrounding nebulous matter.

In the region round the star 12 Monocerotis there is a remarkable nebula of irregular shape, somewhat resembling in its general character the great nebula in the "sword" of Orion. Dr. Roberts, describing a photograph he took of this nebula, says, "Some remarkable tortuous rifts meander through the nebulosity on the *north preceding* half of the nebula; their margins are sharp and well defined in the midst of dense nebulosity. They are as clearly cut as we see the canons of great rivers, but their width may be millions of miles, for we have no reason to assume that the nebula is nearer to the earth than the stars. It is indeed possible that the stars which dot the surface are nearer to us than the nebula."[1]

About 3° north-west of the star θ Canis Majoris is another nebula of irregular form. Dr. Roberts says that the star D.M. 1848 "is on the margin of a dark sinuous vacancy or rift in the nebula, through which we see into the starless vacancy of space beyond it." This opening closely resembles the "key-hole" opening in the great nebula in Argo. Dr. Roberts adds, "These vacancies are most conspicuously seen where the surrounding nebulosity is dense, though they are also visible in some parts where it is relatively faint. The margins of the vacancies are often sharply defined and suggestive of the idea that in consequence of some internal strain, operating from opposite directions,

---

[1] *Knowledge*, June 1, 1899.

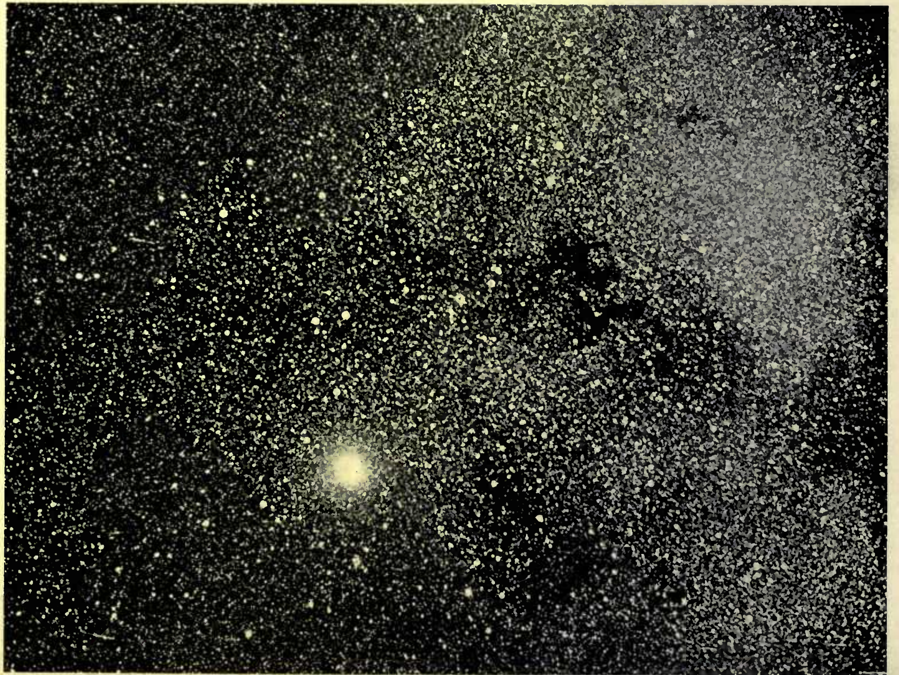

PLATE 1.—THE "TRIPLE CAVE" IN AQUILA.

From an original Photograph by Dr. Max Wolf, Heidelberg. Exposure 10½ hours (6-inch telescope).

the nebula was rent asunder, and the parts separated from each other."[1]

In another nebula in Monoceros, photographed by Dr. Roberts, a little west of the triple star 15 Monocerotis, there is a remarkable vacuity or hole. Dr. Roberts calls it "a dark tortuous rift," and says the rifts prove that the nebulæ are not globular, but are like clouds with relatively small depths, and that we can see through them into the darkness of space beyond." There are also very noticeable areas devoid of stars in the region surrounding this nebula.

A cluster of small stars in Cygnus (N.G.C. 6819) was described by Lord Rosse as "full of holes," and another (N.G.C. 2548) as containing "dark lines and openings."

On July 12, 1891, Dr. Max Wolf, of the Astrophysical Observatory of Heidelberg, discovered three dark markings close together in the Milky Way, about $1\frac{1}{2}°$ west of the star γ Aquilæ. He calls them "the triple caves," and on his photographs they certainly present a very remarkable appearance. Closely east of the same star a photograph taken by Professor Barnard shows some curiously shaped dark markings, which seem to be openings through the stratum of stars composing the Milky Way in this region.

On a photograph by Max Wolf of the region near ξ Cygni there is a remarkable black hole, and some smaller ones.

The question naturally suggests itself, what is the real nature of these curious black spots? Some astronomers have suggested that they are due to masses of cooled-down, or partially cooled-down, matter which absorb the light of the stars behind them. The term "hole," which I have used in the present chapter, implies that my own view is that they are really holes or openings through regions of stars or nebulous matter, and in this view of the matter I am supported by the opinion of several astronomers, as some of the extracts quoted above will show. Photographs of the great "coal sack" near the Southern Cross prove conclusively, I think, that the darkness of this remarkable spot is due to a real paucity of stars compared with the richness of the surrounding regions, and probably the same thing is true of all the other dark spots in the Milky Way. We have really no evidence of the existence of dark bodies in space. Professor Newcomb thinks that there is probably little or no extinction due to dark bodies, and he says, "We may say with certainty that dark bodies are not so numerous as to cut off any important part of the light from the stars of the Milky Way, because if they did, the latter would not be so clearly seen as it is. Since we have reason to believe that the Milky Way comprises the more distant stars of our system, we may feel fairly confident that not much light can be cut off by dark bodies from the most distant regions to which our telescopes can penetrate. Up to this distance we see the stars just as they are."[1] The companions of some of the Algol variables are usually spoken of as "dark bodies," but I have shown elsewhere that we have no reason to think that they are really dark. The companion of Algol, for example, may be a star of the 5th magnitude, and yet be quite invisible to us, as neither

---

[1] *Knowledge*, November 1, 1899.

---

[1] *Harper's Magazine*, October, 1904.

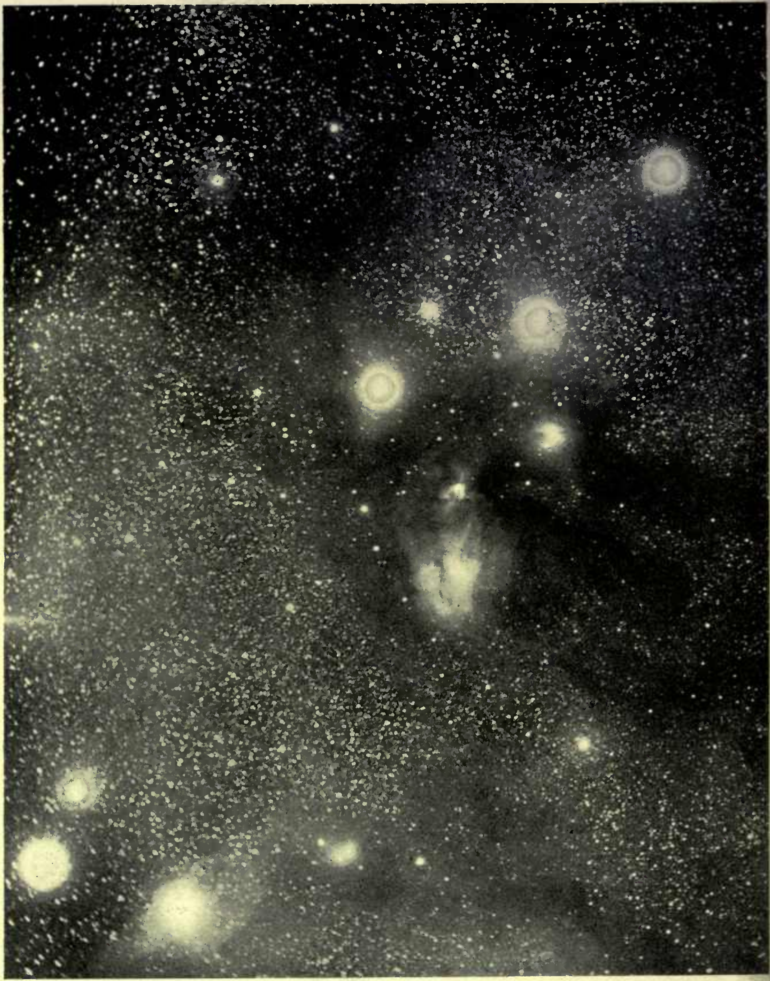

PLATE 2.—GREAT NEBULA NEAR ρ OPHIUCHI.

From a Photograph by Professor E. E. Barnard, Yerkes Observatory.

telescope nor spectroscope would show any trace of its existence. The little evidence we have tends to show that the satellite of Algol is *not* a dark body. The idea of "dark bodies" seems to have been based on the existence of this eclipsing satellite; but it has been recently found that a difference of brightness of two magnitudes between the components of a spectroscopic binary would be quite sufficient to obliterate the spectrum of the fainter star. Dark bodies *may* exist in space, and probably do, but as yet we have no positive evidence of their existence. The "holes in the heavens" are, I think, real, and "dark" companions of Algol variables have probably no existence except in the imagination of some astronomical writers.

It has been stated by several writers that the existence of these "holes" indicates that the Milky Way has, in these parts, a small extension in the line of sight, or, in other words, that it forms a comparatively thin stratum of stars. Sir John Herschel says, "Where we see, as in the coal sack, a sharply defined oval space free from stars, insulated in the midst of a uniform band of not much more than twice its breadth, it would seem much less probable that a conical or tubular hollow traverses the whole of a starry stratum, continuously extended from the eye outwards, than that a *distant* mass of comparatively moderate thickness should be simply perforated from side to side, or that an oval vacuity should be seen foreshortened in a *distant* foreshortened area, not really exceeding two or three times its own breadth."[1] This conclusion, which seems to me correct, is challenged by Professor Seeliger, who shows that, according to the Law of Probability, "the occurrence in the Milky Way of dark places in the midst of stellar accumulations is indeed very improbable, but in every case *the probability remains just as slight if we compress the same number of stars into a smaller space,* if this covers the same portions of the heavens as before."[1] But, if I understand Sir John Herschel's remark correctly, he intended to imply that "in the thick and thin portions of the Milky Way zone the stars are supposed to be *uniformly distributed*"[2] in both cases; and it seems evident—on this assumption—that the occurrence of dark spots in the Galaxy would be more probable where the Milky Way has a small extension in the line of sight than in other places where the thickness may be considerably greater.

---

[1] "Outlines of Astronomy," 10th edition, p. 574.

The cause of these "holes" must, I think, be looked for in the influence of some "clustering power"—as Sir William Herschel termed it—which tends to draw the stars away from certain parts and accumulate them in others. The existence of globular and other clusters close to dark and comparatively starless spots seems very suggestive in this connection. If these dark spots were due to intervening dark bodies, we should expect to find them scattered indifferently in rich and poor regions of the Milky Way, and there seems to be no reason why they should be so often associated with *rich* regions of the Galaxy.

---

[1] *Astrophysical Journal,* vol. 12 (1900), p. 377. The italics are Seeliger's.

[2] That is, the same number of stars per unit of space volume.

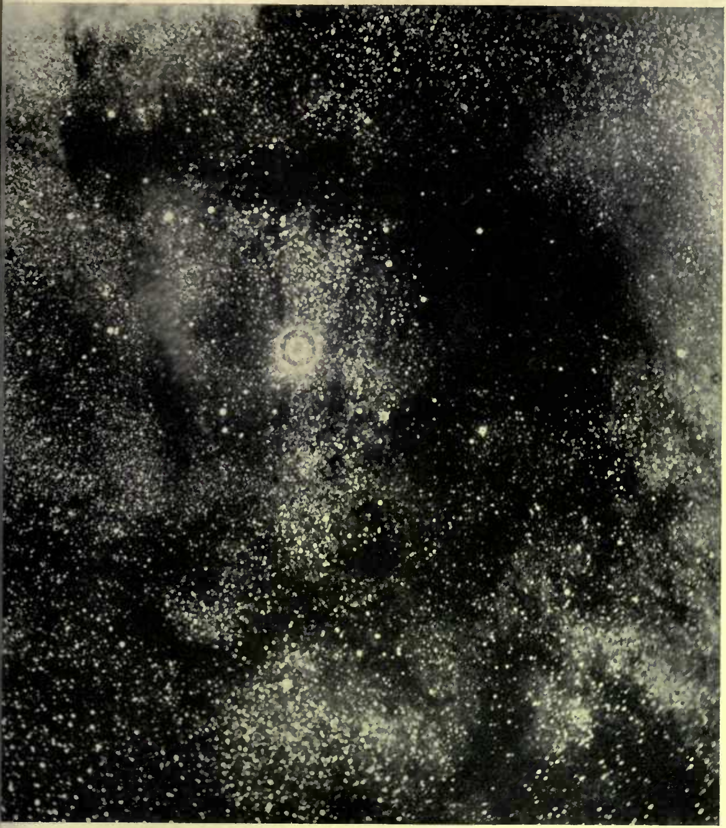

PLATE 3.—THE MILKY WAY ROUND θ OPHIUCHI.

From a Photograph by Professor E. E. Barnard, Yerkes Observatory.

CHAPTER XIX

THE MAGELLANIC CLOUDS

THE Magellanic clouds are two spots of nebulous light of roughly circular form in the southern hemisphere, somewhat resembling in appearance portions of the Milky Way, but quite unconnected with the Galaxy. They seem to have been first described by the famous navigator Magellan, about the year 1520, and hence their name. But the larger of the two was also mentioned by Anghiera in 1515, and by Corsali in a work published in Venice in 1563. They are included by Schiller (1627) in a list of stars in the southern hemisphere. According to Houzeau, Magellan's attention was directed to these celestial "clouds" by the Indians of South America. The natives of Patagonia thought that these luminous spots were composed of the lightest feathers of the ostriches killed in the chase by their ancestors.[1] Houzeau also states—on the authority of Ideler—that the larger cloud was seen by the Persian astronomer Al-Sufi in the tenth century from the south of Arabia and the Red Sea. But this seems doubtful, at least I can find no mention of it in Al-Sufi's "Description of the Fixed Stars." It could not possibly have been seen by him from his station in Persia (Schiraz), as it was below the horizon of the place. These luminous spots were called by the Portuguese the "clouds of Magellan," and by the Dutch the "clouds of the Cape." They were also called "sacks of coal" by the early navigators, but the term "coal sack" is now usually applied to the dark spots or openings visible in various parts of the Milky Way.

---

[1] Prichard, "Physical History of Mankind," third edition, vol. v. p. 490, quoted by Houzeau.

The Magellanic clouds are also called *nubeculæ*, the larger cloud being known as the *nubecula major*, and the smaller the *nubecula minor*. According to Houzeau the smaller cloud is not very noticeable to the naked eye, and its brightness scarcely reaches that of a 6th magnitude star. The larger cloud is much brighter, and about equal in brightness to that of a star of 5–6 magnitude. The larger cloud lies partly in the constellation Dorado and partly in Mensa. It extends from about R.A. 4^h 40^m to R.A. 6^h 0^m, and lies between 66° and 72° south declination. The smaller cloud lies partly in Toucan and partly in Hydrus. It is much smaller in size, and its limits are about R.A. 0^h 28^m and 1^h 15^m, and 72° to 75° south declination.

The *nubeculæ* were carefully examined by Sir John Herschel during his residence at the Cape of Good Hope in the years 1834 to 1838, and he gives an account of his observations in his interesting and valuable volume usually known as the "Cape Observations." He determined the position of 919 stars, nebulæ, and clusters in the *nubecula major*, and 244 objects in the *nubecula minor*. He describes the larger cloud as consisting "partly of large tracts and ill-defined patches of irresolvable nebula and nebulosity in every stage of resolution up to perfectly resolved stars like the Milky Way, as also of regular and irregular nebulæ properly so called, of globular clusters in every stage of resolvability, and of clustering groups sufficiently insulated and condensed to come under the designation of 'clusters of stars' in the sense of which that expression is always to be understood in reading my father's or my own catalogues." It covers an area of about 42 square degrees, and contains about 278 clusters and nebulæ. It is thus very rich in these objects, and Sir John Herschel says, "Even the most crowded parts of the stratum of Virgo, in the wing of that constellation, or in Coma Berenices, offer nothing aproaching to it. It is evident from this, and from the intermixture of stars and unresolved nebulosity, which probably might be resolved with a higher optical power, that the nubeculæ are to be regarded as systems *sui generis*, and which have no analogues in our hemisphere." One of the nebulæ contained in this extraordinary collection of objects, Sir John Herschel describes as "very bright; very large; oval; very gradually pretty much brighter in the middle; a beautiful nebula; it has very much resemblance to the *nubecula major* itself as seen with the naked eye, but it is far brighter and more impressive in its general aspect as if the nubecula were at least doubled in intensity," and he adds, "And who can say whether in this object, magnified and analyzed by telescopes infinitely superior to what we now possess, there may not exist all the complexity of detail that the nubecula itself presents to *our* examination?"

Among many other remarkable objects contained in the *nubecula major*, we may mention the great "looped nebula" 30 (Bode) Doradus, of which Sir John Herschel gives a beautiful drawing. He describes it as "one of the most singular and extraordinary objects which the heavens present." Near the centre of this nebula is a star of the 9th magnitude, forming with some fainter stars a small cluster. Immediately south of this is a pear-shaped opening, somewhat similar to the "key-hole" perforation in the great nebula round η Argus, but of proportionately larger dimensions. North of the central star there is a bright nebulous ray like the tail of a comet. Near this is a round hole, and a little further north three plumes like branches diverge from a common nebulous stem. The fainter portions of the surrounding nebulosity seem to be also pierced by similar "coal sacks," features which appear to be characteristic of these irregular-shaped nebulæ. Many faint stars are scattered over this nebula, and Sir John Herschel gives a catalogue of these ranging in brightness from the 10th to the 17th magnitude. He found the nebulosity to be quite irresolvable into stars, and it is probably gaseous. It covers an area of about one-fifth of a square degree, or about the area of the full moon. Near it are two large and rich clusters. There are many other remarkable nebulæ and groups of nebulæ in the *nubecula major*. Sir John Herschel found the zone south of the nubecula "dark and starless."

The smaller cloud, or *nubecula minor*, is only about one-fourth the apparent size of the other, and covers an area of about 10 square degrees. It is not connected in any way with the larger cloud, or the Milky Way. To the naked eye it is of apparent uniform brightness. The surrounding regions are remarkably free from stars. Sir John Herschel says, "The access to the Nubecula Minor on all sides is through a desert." Examined with his large reflecting telescope, he found it to be "a fine, rich, large cluster of very small stars, 12 . . . 18 magnitude, which fills more than many fields, and is broken into many knots, groups, and straggling branches, but the *whole* (*i.e.* the whole of the clustering part) is clearly resolved." In addition to the stars, there are numbers of nebulæ and clusters.

Closely preceding (that is, west of) the smaller cloud is the magnificent globular cluster known as 47 Toucani. It was discovered by Lacaille in 1752. He described it as "a nebula without stars; it resembles the nucleus of a small comet, and is visible with a telescope of 2 feet in length." It is visible to the naked eye as a star of about 4½ magnitude. Sir John Herschel says "it is *completely insulated*"—that is, although so close to the nubecula, it has apparently no connection with it. It has a more condensed central portion, which Sir John Herschel saw, of a "pale pinkish or rose colour . . . which contrasts evidently with the white light of the rest." He estimated its diameter at 15 to 20 minutes of arc, with the stars nearly equal, and of 12th to 14th magnitude. On a photograph of this cluster taken by the Harvard observers at Arequipa, Peru, over 2000 stars were counted within 11 minutes of arc of the centre of the cluster. Six variable stars have been detected in this cluster at the Harvard Observatory.

The Magellanic clouds have been photographed by Mr. H. C. Russell at the Sydney Observatory, and also by the Harvard observers at Arequipa. These photographs show that the larger cloud is probably a vast spiral structure, and Professor Pickering thinks that the nebula 30 Doradus, described above, forms the nucleus of the spiral. Mr. Russell calls it "the grandest spiral structure in the heavens." The *nubecula minor* also seems to be spiral in structure, but this is not so clearly marked as in the larger cloud. Photographs of the larger cloud taken at Harvard show about 300,000 stars.

No less than 152 variable stars have been discovered in the larger cloud at Harvard on photographic plates taken with the 24-inch Bruce telescope at Arequipa. The variation of nearly all these is rapid, and about half of them occur in groups. This grouping of variable stars seems to be a characteristic of these curious objects. I have pointed out this peculiarity elsewhere. The new variables are faint, and the amount of light variation usually small. Some of them, however, show larger fluctuations of brightness. A few have a variation of about two magnitudes, and one of about four magnitudes (11½ to 15½). The period of this variable is probably long. In one curious case near the centre of the "cloud" there are two stars of about the 15th magnitude which seem to be alternately variable, "one is always bright when the other is faint. Period probably short."[1] In the smaller cloud no less than 910 variable stars have been detected at Harvard. Professor Pickering says, "It is estimated that the number of stars photographed in the small Magellanic cloud is about 280,000, of which 910, or one in 308, is variable. . . . It is very difficult to count the faint stars which crowd the background, on account of their closeness to one another, and the number is certainly underestimated."[1]

---

[1] Harvard College, *Observatory Circular*, No. 82.

It was pointed out by Sir John Herschel that the real form of the Magellanic clouds is, in all probability, roughly globular. For otherwise we should be obliged to consider them as cylindrical, with their axes pointing directly towards the earth. This might be possible in *one* case, but that two such objects should exist is utterly improbable. Admitting that they are of a spherical form, we have the curious fact that within a comparatively limited space there exist stars, clusters, and nebulæ, apparently mixed up, and not differing much in their distance from the earth. If we take the apparent diameter of the larger cloud as 7°, we have its real diameter about one-eighth of its distance from the earth, whatever that may be. This would make the distance of the nearest and farthest parts of the "cloud" in the proportion of 15 to 17.

As to the real dimensions of these wonderful objects it is not easy to form even an approximate estimate. So far as I know, no parallax has yet been found for any object contained in the "clouds." Assuming a parallax of one-thousandth of a second of arc for the larger cloud, its distance would be about 200 million times the sun's distance from the earth. This would make its real diameter about 25 million times the sun's distance, or about 45 times the distance of Sirius from the earth. This is, of course, an enormous diameter, but not improbably so when we consider the large number of different objects contained in the cloud. The sun, if removed to the distance found above, would be reduced to a star of about the 15th magnitude. The majority of the stars in the cloud are perhaps brighter than this, and as we can hardly suppose that *most* of them are larger than the sun, we may perhaps conclude that its distance is not greater than supposed above—a sufficiently vast distance, however, considering that it implies a light journey of over 3000 years!

---

[1] *Astronomische Nachrichten*, No. 4032.

Taking the apparent diameter of the large cloud at 7°, and the number of stars it contains as 300,000, I find that the *average* distance between the component stars would be about 9½ "light years," or more than the distance of Sirius from the earth. For the smaller cloud I find an average distance of about five years, or a little more than the distance between α Centauri and the earth.

The association of such diverse objects as stars, clusters, and gaseous nebulæ in the Magellanic clouds shows that all these objects can coexist in a comparatively limited space, and renders it highly probable that all the visible objects in the heavens belong to one and the same sidereal system, and that none of the nebulæ can be considered as "external galaxies." If such "island universes" exist in space, they are probably quite invisible from the earth, and may perhaps lie at such a vast distance that no telescope which could ever be constructed by man would be sufficiently powerful to reveal their existence. Sir John Herschel suggested in a letter to Proctor[1] that our stellar system "may contain within itself miniatures of itself," and the Magellanic clouds are probably examples of this relation on a large scale.

---

[1] *Knowledge*, November, 1885, p. 21.

The star A.G.C. 6886 in the large cloud was found at Harvard to have the large proper motion of 1·28 second per annum. As a large proper motion usually indicates comparative proximity to the earth, this star may possibly lie between us and the cloud. During an examination of photographs of the smaller cloud for variable stars, a star of about the 13th magnitude was found at Harvard to have the comparatively large motion of 0·73 second per annum. Professor Pickering says, "No such motion has heretofore been detected in so faint a star." This large motion may indicate that this small star is much nearer to the earth than the cloud. Its position for 1900 is R.A. 1^h 6^m 1^s, Dec. S 72° 45·5′.

CHAPTER XX

THE RINGED PLANET

"Redeunt saturnia regna."[1]

SATURN, the ringed planet, is the most interesting and wonderful member of the solar system. Next to Jupiter, it is the largest of all the planets, and its rings render it quite an unique object. Its mean distance from the sun is about 886 millions of miles, and it revolves round the central luminary in a period of 10,759 days, or 29 years 167 days. The eccentricity of the orbit is 0·0560713, and its inclination to the ecliptic 2° 29′ 40″. According to micrometrical measures made by Professor Barnard with the great Lick telescope of 36 inches' aperture, the equatorial diameter of the planet is 76,470 miles, and the polar diameter 69,770 miles. It is therefore considerably flattened at the poles, and this polar compression is very noticeable in a good telescope. The mass of Saturn is about $\frac{1}{3500}$ of the sun's mass. In volume it is over 700 times that of the earth, but in density it is very light, about 0·7 that of water. Its period of rotation on its axis is, according to Professor Asaph Hall, $10^h\ 14^m\ 24^s$. This is for the equator, but the "north temperature zone" of the planet seems to have a slower rotation, for Denning finds $10^h\ 38^m$, and Comas Sola $10^h\ 38{\cdot}4^m$. A bright spot in the northern hemisphere of the planet observed by Barnard in 1903 gave a period of $10^h\ 39^m$. A similar difference has been observed on Jupiter, but not to so great an extent. The light reflecting power of its surface, or "albedo," as it is termed, is about 0·50 (a perfect reflection = 1), but Müller finds 0·72. Like Jupiter, it is probably in a very heated condition, but possibly its surface temperature is not so high as to produce any inherent light of its own. Its surface does not seem to be so disturbed as that of Jupiter. It does not show such well-marked belts and spots and other markings as make the "giant planet" such an interesting object in the telescope. "Belts" are fairly visible in good telescopes, but, according to Denning, well-defined irregular markings are rare on the disc of Saturn. Professor Asaph Hall saw a marking of this kind in December, 1877; but Barnard with the 36-inch Lick telescope, Young with 23-inch, and Hough with 18½-inch refractor, failed to see any spots. Some round spots were observed by Denning and Stanley Williams, but Barnard finds that spots observed with smaller telescopes are not visible with the great Lick telescope!

---

[1] Virgil, Eclogues, iv. 6.

Saturn is probably in an earlier stage of planetary evolution than Jupiter is. Its small density shows this. It is lighter than water, and would float in it. As it must be much denser nearer the centre, its outer surface is probably in the gaseous state. It has been objected that if Jupiter and Saturn were highly heated they would have a reddish colour. But they may be very hot and have some inherent light without being actually *red* hot. It was shown by H. F. Weber in 1888 that filaments of platinum, gold, and iron, when heated, give a "gray glow," which "is evident at temperatures much below that of dull red, namely, 525°. Gold gives the gray effect at 417°, iron at 377°, and platinum at 390°.[1] M. Rogovsky thinks that Saturn, Uranus, and Neptune have high temperatures, but "considerably lower than that of Jupiter." He thinks that the great albedo of Saturn found by Müller "may be caused by the reflection from its clouds being more perfect than that of Jupiter, which is enveloped probably by vapours of denser substances."[2] But Zöllner found the albedo of Saturn less than that of Jupiter.

Owing to Saturn's great distance from the sun, the light and heat received from the central luminary will only amount to about $\frac{1}{90}$ of that received by the earth. The sun would show an apparent diameter of only 3′ 22″, and its disc would therefore be hardly visible to the naked eye. Of the planets nearer to the sun than Saturn, the only one visible would be Jupiter, all the others remaining permanently invisible, owing to their small size and proximity to the sun. Jupiter would be seen alternately as a morning and evening star, and would show phases similar to those of Venus, but would never form such a brilliant object in the sky of Saturn as he is to us when in opposition, his greatest apparent elongation from the sun being only 33°, or about 12° less than that of Venus, as seen from the earth. Uranus would be visible from Saturn as a star of about the 4th magnitude, but Neptune would not be within range of naked-eye vision such as ours.

---

[1] *Nature*, February 2, 1888, p. 331.

[2] *Astrophysical Journal*, vol. 14, p. 249.

Saturn is attended by a retinue of 10 satellites. These have been named Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Themis, Hyperion, Iapetus, and Phœbe. This is the order of their distance from the planet, Mimas being the nearest and the recently discovered Phœbe the farthest. Titan, the largest of the satellites, was discovered by Huygens in 1655, Iapetus by J. D. Cassini in 1671, Rhea also by Cassini in 1672, and Tethys and Dione by the same famous observer in 1684. Mimas and Enceladus were found by Sir William Herschel in 1789, Hyperion by G. P. Bond in America, and independently by Lassell and Dawes in England in 1848, Phœbe by Professor W. H. Pickering in 1898, and Themis also by W. H. Pickering in 1904. The mean distances of the satellites from the centre of Saturn are approximately as follows: Mimas 117,000 miles, Enceladus 157,000, Tethys 186,000, Dione 238,000, Rhea 332,000, Titan 771,000, Themis 906,000, Hyperion 934,000, Iapetus 2,225,000, and Phœbe about eight millions of miles. Their periods of revolution round Saturn are: Mimas $22^{h}\ 37^{m}$, Enceladus $1^{d}\ 3^{h}\ 53^{m}$, Tethys $1^{d}\ 21^{h}\ 18^{m}$, Dione $2^{d}\ 17^{h}\ 41^{m}$, Rhea $4^{d}\ 12^{h}\ 25^{m}$, Titan $15^{d}\ 22^{h}\ 41^{m}$, Themis $20^{d}\ 20^{h}\ 24^{m}$, Hyperion $21^{d}\ 6^{h}\ 39^{m}$, Iapetus $79^{d}\ 7^{h}\ 54^{m}$, and Phœbe about 546½ days. With the exception of the two outer satellites, the periods of revolution are less than that of our moon. Their diameters are somewhat doubtful. That of Mimas is perhaps about 600 miles, Enceladus 800, Tethys 1200, Dione 1100, Rhea 1500, Titan 2500, Themis 38, Hyperion 500, Iapetus 2000, and Phœbe perhaps 42 miles. The orbit of Themis is inclined about 39° to the plane of the ecliptic, but the others have a smaller inclination. The orbits are nearly circular with the exception of

Hyperion, which has an eccentricity of about 0·12, that of Phœbe 0·22, and of Themis 0·23. Owing to their great distance from the sun and the diminished intensity of sunlight, the combined light of all these moons, as seen from Saturn, would be small.

Seen from Mimas, the globe of Saturn would appear as a large disc of about 33° in diameter. From Enceladus it would have an apparent diameter of about 25½°, from Tethys about 20½°, from Dione 16°, from Rhea 11½°, from Titan 5°, from Themis and Hyperion about 4°, and from Iapetus about 1·7°. Even from the distant Phœbe, Saturn would show a disc of about 28 minutes, or nearly as large as our moon.

The new satellite Phœbe was discovered by means of photography. In the year 1888 a photographic search for a ninth satellite of Saturn was made by Professor W. H. Pickering, of the Harvard Observatory, at the station at Arequipa, Peru, with a 13-inch telescope, but without success. The satellite was discovered in August, 1898, on plates taken with the 24-inch Bruce telescope. It appeared as a small star of about 16th magnitude, and its detection among a crowd of small stars was a matter of no small difficulty. The satellite was again photographed in the years 1900, 1902, and 1904. The eccentricity of the orbit is, as has been said above, about 0·22, an unusually large eccentricity for a satellite, and about equal to that of the minor planet Eros. The period of revolution is about 546½ days, or "about one day short of a year and a half"—an unusually long period for a satellite. Its mean distance from Saturn is about 8 millions of miles, but owing to the eccentricity of the orbit, this distance varies from about $6\frac{1}{4}$ to $9\frac{3}{4}$ millions of miles. The motion in its orbit is retrograde, or in an opposite direction to that of the other satellites. At first sight this would appear inconsistent with Laplace's nebular hypothesis, but Professor Pickering points out that very possibly the rotation of Saturn, when in the gaseous state, was originally in a retrograde direction, but that owing to tidal action this retrograde motion was reversed—*after* the formation of Phœbe. From this point of view the retrograde motion of Phœbe would be merely a survival of the original motion of the primitive nebulous mass from which Saturn and his satellites were evolved. The motion of the lately discovered sixth and seventh satellites of Jupiter is, however, direct, and this fact is unfavourable to Professor Pickering's hypothesis. The diameter of Phœbe is probably about 42 miles. Seen from Saturn, its brightness would vary from about the 5th to the 6th magnitude.

The tenth satellite, Themis (so named after one of the sisters of the god Saturn), was discovered on photographic plates by Professor W. H. Pickering, in 1904. Its apparent magnitude is about $17\frac{1}{2}$. It is therefore the faintest known member of the solar system, and is invisible to the eye with the largest telescope yet constructed. Professor Pickering says that "a ball of rather less than one inch in diameter at a distance of 3000 miles would reflect as much light to us as Phœbe or Themis."

The satellite Titan, as seen from the earth, shines as a star of about $8\frac{1}{2}$ magnitude, and is easily visible in a 3-inch telescope. From observations in 1892, M. L. Radeaux found that its brightness varies about half a magnitude, from 8·0 to 8·5, and this fluctuation of light seems to occur regularly. The period of rotation is like our moon—probably equal to the time of revolution round Saturn. He finds that all the satellites of Saturn—at least the larger ones—have periods of rotation equal to their respective periods of revolution. The variation of light is, he thinks, due to dark spots on their surface as their light varies periodically with the satellite's position in its orbit. Iapetus varies from about the 9th to the 11th magnitude. This was confirmed by Dr. See, who thinks that "only one side gives sufficient light to enable the observer to recognize a disc." The disc is visible when the satellite precedes the planet. Dr. Guthnick finds that Dione and Tethys vary about 0·75 magnitude, and Rhea about 1 magnitude. The small satellite Phœbe varies about $1\frac{1}{2}$ magnitude, according to Professor Pickering, but the light of Themis seems to be constant.

There is a wide gap between Titan and Iapetus, in which there are two small satellites, Themis and Hyperion, and Ledger suggested that there may be others in this interval. But the gap between Iapetus and Phœbe is still wider, and other faint satellites may yet be discovered. Hyperion is very faint, about 13th magnitude. Its orbit is much disturbed by the attraction of Titan. Hussey finds from his own observations that Mimas is probably larger than Hyperion, and that the supposed diameter of Titan is too large. He estimates it to be about 2500 miles.

Saturn and its satellites form a most interesting system, but the most remarkable and wonderful feature about Saturn is the marvellous system of luminous rings which surround the planet. This extraordinary appendage is quite unique in the solar system, and consists of three flat circular rings, of very small thickness in proportion to their extent, completely surrounding the planet, but nowhere touching it, in fact, poised in space like Saturn itself, and, like the satellites, revolving round the planet. The outer ring, known as ring A, is somewhat fainter than the middle ring, from which it is separated by a narrow dark division, discovered by Cassini in 1675, and hence called "Cassini's division." This middle ring is brighter on the outside, and fades gradually towards the planet, merging on its inner edge into a dusky or semi-luminous ring, termed the "gauze" or "crape" ring, also known as ring C. The existence of this dusky ring was only discovered in the year 1850, independently by Bond in America and Dawes in England, and seems to have entirely escaped the notice of the Herschels and other careful observers.

From observations made at Poulkova in 1850–51, compared with former observations, Struve concluded that the outer ring remained constant, but that the inner diameter of the middle ring decreased at the rate of 1·25 second a century. Further measures by Struve to test this supposed change in 1881–82 showed a decrease of only 0·04 second in 31 years. Seagrave, in 1904, found by measures made by himself, compared with those of good observers in the last 75 to 80 years, that there is no constant decrease, and he thinks that Struve's theory should now be abandoned. The earlier observations were made with inferior instruments, and are therefore not reliable.[1] The following dimensions of the ring system are given by Professor Barnard from micrometrical measures made with the great Lick telescope:—

Outer diameter of outer ring . . .	172,310	miles
Inner diameter of outer ring . . .	150,560	,,
Outer diameter of inner ring (B) . .	146,020	,,
Inner diameter of inner ring . . .	110,200	,,
Inner diameter of crape ring . . .	88,190	,,
Width of Cassini division	2,270	,,

The mass of the ring system is very small. Tisserand estimated it as $\frac{1}{620}$ of the mass of Saturn; but it is probably very much less than this. Hermann Struve has shown that the mass is inappreciable, as it produces no effect on the motions of the satellites, and he calls the rings "immaterial light." They must, however, have *some* small mass, as they are quite opaque; at least, the bright rings. The "crape ring" is, however, partly transparent, as the body of the planet is visible through it. M. Antoniadi, the well-known French astronomer, thinks that the crape ring is not really a dark ring, but that its apparent darkness is simply due to the smaller number of the individual particles composing the ring,[2] and that the shade thrown by the ring on the ball of the planet is probably due to "penumbral shadows," the particles being too small to cast real shadows.

The thickness of the ring system is very small. Sir William Herschel found 856 miles, and Schroter 539 miles. But these estimates are certainly too large. The Bonds found the thickness less than 43 miles, but Trouvelot thought this estimate too small. The ring system must, however, be very thin, for in 1892, when the plane of rings passed between the earth and sun, the rings were completely invisible in the great Lick telescope.

---

[1] *Popular Astronomy*, February, 1904.

[2] *Monthly Notices*, R.A.S., May, 1899, and supplementary number.

The plane of the rings, which probably coincides with that of Saturn's equator, is inclined to the plane of the ecliptic at an angle of about 28°. As the plane of the ring system always remains parallel to a fixed plane during the planet's revolution round the sun, this plane will at Saturn's equinoxes pass through the earth at intervals of $14\frac{3}{4}$ years (half the period of revolution). The rings then disappear.

Several divisions, or partial divisions, have been observed from time to time in the bright rings. One in the outer ring (A), known as Encke's division, has been seen by several observers. It was seen by Mr. C. Roberts with a $6\frac{1}{4}$-inch mirror in April, 1896. He found it decidedly outside the centre of the ring. It was also seen by M. Leo Brenner in the same month. It was also seen by Ph. Fauth in June, 1897, with a 7-inch refractor.[1] Keeler, in 1888, detected a very fine division in the outer ring (A) with the Lick telescope. It was about one-sixth of the breadth of the ring from its outer edge. Some dark radial markings were seen by Antoniadi on the outer ring in April, 1896, with $9\frac{3}{4}$-inch object glass, and four concentric markings on the middle ring (B). In 1897 Professor Schaeberle detected a partial division in the middle ring. It was 0·7 second from the inner edge of the ring, and of about the same width as the Cassini division. Barnard considers that the so-called Encke's division in the outer ring is not a real division, but merely a marking. M. Leo Brenner saw a division between the middle ring and the "crape ring," but this Schaeberle failed to see.

---

[1] *Astronomische Nachrichten*, No. 3436.

Seen from Saturn, the whole system of rings would disappear below the horizon at a Saturnian latitude of about 66°. It is fortunate for us that the earth does not possess such an appendage as Saturn's rings, for although they form a beautiful spectacle as seen from our standpoint, they produce numerous eclipses of the sun as seen from Saturn—eclipses lasting in some latitudes for over a year! An observer on any of the larger satellites would see the rings edgeways as a line of light across the planet's disc; and, viewed from Saturn's equator, they would appear as a line of light across the sky.

Professor Vogel found some years ago a strong absorption band in the spectrum of Saturn which was very faint or absent in the spectrum of the rings. This observation was confirmed by Mr. Ellerman at the Yerkes Observatory in August, 1898. From this Professor Hale concludes that the rings have no atmosphere, thus confirming the results formerly found from visual observations. Indeed, this result might well have been anticipated from the small mass of the ring system, which would be incapable of retaining an atmosphere owing to its small power of attraction.

The constitution of these wonderful rings was for a long time a matter of mystery. Proctor has well shown that the thickness is so small in comparison with the vast dimensions of the rings that even if composed of wrought iron they would form very flimsy bodies indeed, utterly unable to resist the enormous strains to which they would be subjected by their rotation round the planet. That they must rotate round Saturn is obvious, for if they were not rotating, the enormous attraction of Saturn's mass would soon shatter them to pieces, and precipitate the fragments on the planet's equatorial regions. Laplace found by mathematical analysis that the stability of the rings could not be maintained unless their mass was distributed unequally, but he did not determine what arrangement of weight would be necessary to ensure stability. Professor Bond, in 1851, pointed out that the changes observed in the aspect of the rings, especially the appearance of divisions, was inconsistent with a solid constitution. Bond's views were confirmed mathematically by Professor Peirce, of Harvard University, but the latter thought that they might possibly be liquid. It seems, however, to the present writer that Peirce overlooked the consideration that the cold at Saturn's great distance from the sun would freeze them solid if formed of any ordinary liquid. In 1857 Professor Clerk Maxwell investigated the question in an essay written for the Adams Prize, and he showed clearly that the rings could be neither solid nor liquid, and that they must consequently consist of a multitude of separate solid particles, each revolving in its own orbit round the planet. This theory was originally suggested by Roberval in the seventeenth century, by J. Cassini in 1715, and by Thomas Wright of Durham in 1750. It was Wright who originally suggested the so-called "disc theory" of the Milky Way, usually, but erroneously, attributed to Sir William Herschel. In 1888 Professor Seeliger pointed out that the constant brightness of the rings at all angles of solar illumination could only be explained on the satellite theory. The theory was finally confirmed by Professor Keeler by spectroscopic observations in 1895. The photographed spectrum of Saturn and the ring system showed that the velocity of the planet's limb was about 6·4 miles a second, and the mean velocity of the rings about 11·2 miles a second. It further showed that the velocity of the inner edge of the bright rings is greater than that of the outer edge, and that within the limits of error of the method used the relative velocities of the different parts of the ring system are such as satisfy Kepler's third law of motion.[1] According to Kepler's law, the nearer a satellite is to a planet the greater should be its velocity, and as this is the case in Saturn's rings, we may safely conclude that the rings consist of a multitude of small bodies, each revolving in its own orbit round the planet. Were the rings solid, the velocity at the outer edge would evidently be greater than on the inner edge, and this is the reverse of what the spectroscope shows. Keeler's results were fully confirmed by Belopolsky, Campbell, and Deslandres, and the constitution of the rings is no longer a mystery. These little bodies are so small and numerous that they present the appearance of a continuous surface in the telescope. The thinness of the rings is at once explained by this theory, for the attraction of Saturn's protuberant equator would compel each of the little satellites composing the rings to travel in or near the plane of the planet's equator.

It was shown by Kirkwood in 1867 that the

---

[1] *Nature*, June 13, 1895.

Cassini division is due to the disturbances produced by the attractions of the large satellites, and this conclusion was confirmed by Meyer. Trouvelot thought that the observations of Perkins, Offord, Davis, Stanley Williams, Stroobant, and others confirmed his opinion that, "so far from being stable, the rings of Saturn are, on the contrary, essentially variable, and subject to continual fluctuations." Proctor has shown that the disturbing forces acting on the rings—caused chiefly by the attractions of the large satellites—would produce a series of waves, the effects of which might occasionally become visible in the form of "a temporary division or dusky stripe," like Encke's division in the outer ring.

CHAPTER XXI

THE STELLAR UNIVERSE

THAT our *visible* universe is limited in extent there is ample evidence to show. The number of stars visible to the naked eye is not only comparatively small, but absolutely so; and the number which will appear on the photographic charts of the sky, now in progress, will probably not exceed 100 millions. And even this large number is comparatively small. The richest man in the world is said to possess as many sovereigns; and in a ten-acre field of ripe oats the number of grains of corn probably exceeds the number of the visible stars. Taking the population at 1500 millions, we have the remarkable fact that for every star in the sky there are fifteen human beings living on our little globe.

The number of stars visible to the naked eye has been variously estimated. The photometric measures made at Harvard Observatory show the following figures: under magnitude 2, 38 stars; under 3·0, 99; under 4·0, 317; under 5·0, 1020; and under 6·0, 2805; total, 4339 to the 6th magnitude, which is about the faintest distinctly visible to average eyesight. The coefficient of increase for each magnitude is about 3; that is, the total number down to any given magnitude is about three times the number of stars brighter than that magnitude.

According to Professor Newcomb, there is no evidence of a decrease in this coefficient to the 10th magnitude. But a diminution in the rate of increase must set in somewhere below the 10th magnitude, for otherwise the number of the visible stars would be considerably greater than it actually is. Taking the number of stars down to the 6th magnitude as 4339, and assuming a factor of 3 for the total number to each magnitude below this, I find that the total number down to the 15th magnitude should be about 85 millions; to the 16th magnitude about 256 millions; and to the 17th magnitude—about the faintest visible in the great Yerkes telescope—about 768 millions. It is evident, therefore, that there must be a diminution, or "thinning out," of the visible stars at some point in space. This diminution in the increase probably begins with stars of the 10th or 11th magnitude. Now, what is the cause of this decrease in number as the stars become fainter? Is it due to an actual decrease in number as we approach the limits of the visible universe, or is it caused by an extinction of light in the ether of space? The latter seems improbable, for Professor Seeliger finds that stars of the 11th and 11½ magnitude are comparatively few in number near the poles of the Milky Way, but are very numerous in the Galaxy itself. This is also true for fainter stars such as those seen by Sir William Herschel in his "gages." Photographs give similar results. Dr. Roberts's photographs of the Milky Way in Cygnus and elsewhere show over 5000 stars to the square degree, while a photograph taken near the North Galactic pole shows only 178 stars to the square degree, the average for the whole sky being about 1500. It seems reasonable, therefore, to conclude that if faint stars are apparently few in number near the poles of the Milky Way, the real reason is that the stars are *not there*, and that, in this region at least, there is real "thinning out" of the stars at a certain distance from the earth. It is clear that if absorption of light by the ether had any real or at least appreciable effect, it would have the same effect in the direction of the Milky Way as in that of the Galactic poles. We must therefore conclude that the paucity of stars near the poles of the Milky Way indicates that the stars are really few in number in that direction, and that here, at least, the visible universe of stars is limited. And it seems highly probable, and indeed we may say certain, that even in the direction of the Milky Way itself the stars thin out beyond a certain distance and do not extend indefinitely into space, for if they did, the Galaxy would be much brighter than it actually is.

Now let us consider what is the probable extent of the visible universe. The faintest stars visible on photographs are probably about the 18th magnitude; that is, about one magnitude fainter than the faintest visible in the Yerkes telescope. Assuming this magnitude and taking the sun's stellar magnitude as $-26{\cdot}5$, I find that to reduce the sun's brightness to that of these faint stars it should be removed to a distance represented by about 12,500 years' journey for light. The sun, if placed at the distance of Sirius (parallax = 0·37 second), would shine as a star of about 2·22 magnitude, or 3·8 magnitudes fainter than Sirius appears to us. From this it follows that Sirius is about 33 times brighter than the sun. Sirius might therefore be removed to 5·75 times ($\sqrt{33}$) its present distance and still shine as a star of 2·22 magnitude; and to reduce it to a star of the 18th magnitude it should be removed to 8241 times its present distance. This would represent a light journey of about 72,000 years. If, therefore, any of the 18th magnitude stars in the Milky Way are suns similar to Sirius—that is, of the same size and intrinsic brightness—they may lie at a distance of 72,000 "light years" from the earth. That is, provided that light suffers no extinction in traversing this vast distance. And if similar to our sun, they may be at a distance of our 12,000 years' journey for light.

There seems to be evidence, however, that the greater portion of the light of the Milky Way does not come from these faint stars, but from stars considerably brighter. Mr. C. Easton finds, from an examination of a photographic plate of a very brilliant region of the Milky Way to the south of the bright star γ Cygni, that about half the total light of the Milky Way in this region comes from stars of the 9th to 12th magnitude. From this he concludes that neither the bright telescopic stars (6th to 9th magnitude) nor the very faint stars (below 12th magnitude) have any great influence in producing the light of the Galaxy. From an investigation of a much fainter portion of the Milky Way he finds the same result.[1] This agrees with my own computations of the total brightness of starlight, which show that the greatest amount of the light comes from stars of the 9th to 12th magnitude.[2] Easton also thinks it "extremely probable that the great majority of the faintest stars of the Milky Way—so far as their existence is revealed to us by photography or direct vision—are not much more distant from us than stars of the 9th or 10th magnitude, at least in the regions to which our researches have extended."[1]

---

[1] *Knowledge*, July, 1903.

[2] *Ibid.*, August, 1901.

Professor Newcomb thinks that there is evidence to show that the stars of the Milky Way are probably situated at a distance between 100 million and 200 million times the sun's distance from the earth. These distances correspond to 1579 and 3159 years of light travel. Placed at the greater of these distances, I find that the sun would be reduced in brightness to a star of the 15th magnitude.

There seems to be evidence that the faint stars of the Milky Way have spectra of the Sirian type. Supposing with Easton that the fainter stars of the Milky Way are of the 12th magnitude, and further, that they are comparable with Sirius in size and brightness, I find that their distance would be represented by about 4600 years of light travel. But Sirius is perhaps a larger body than an average Galactic star. Its mass is about two and a half times the mass of the sun, and its total brightness about 33 times greater. Possibly the stars of the Milky Way may be much smaller. Professor Kapteyn—a great authority on this subject—finds, from an investigation of the probable distance and brightness of a number of stars of various magnitudes, that in a volume of space containing two millions of stars of the same luminosity as the sun, there would probably be about half a million brighter than the sun, and about 12½ millions of smaller luminosity; that is, out of a total of 15 millions of stars, about 12½ millions would be smaller than our sun.

---

[1] *Knowledge*, August, 1895.

To reduce the sun to the brightness of a star of the 12th magnitude, it should be removed to a distance of about 790 "light years." Considering thirteen stars, for which fairly reliable parallaxes have been found, I find that the average distance of these stars, if removed to a distance which would reduce their light to the 12th magnitude, would be 2921 "light years." As these stars are of various sizes and brightness—their "relative brightness," compared with the sun, ranging from 0·122 to 128[1]—we may perhaps assume that they represent nearly all classes of stars, and the average distance of 12th magnitude stars is about 3000 "light years."

If we assume that the stars of the Milky Way are much smaller than Sirius, say one-half the mass of the sun, or one-fifth of the mass of Sirius, I find that the distance of 12th magnitude stars would be —if of the same density and surface luminosity as Sirius—about 2700 "light years." Assuming with Newcomb that the outer boundary of the Milky Way is at about 3000 light years, let us see what average distance this will give between each pair of stars, on the supposition of an equal distribution of stars in a globular space. We know, of course, that the visible stars are *not equally distributed*, but the calculation will give the *average* distance between any two adjacent stars. Assuming a total of 100 millions, and that each star is placed at the angle of a tetrahedron, I find that the average distance between two stars would be about 21·24 light years. This corresponds to a parallax of 0·153 second. Now, I find that the average parallax of the thirteen stars referred to above is 0·243 second. If we exclude four stars with a parallax of over 0·3 second—which may perhaps be considered as exceptionally near our system—we have nine stars with an average parallax of 0·155 second.

---

[1] See my paper on "The Relative Brightness of Stars" in *Monthly Notices*, Royal Astronomical Society, January, 1905.

With a distance of 21·24 light years between two adjacent stars at a distance of 3000 light years from the earth, I find that the apparent distance between such stars in the Milky Way would be about 24 minutes of arc, and as the stars in the Galaxy are, on an average, much closer than this, it seems highly probable that the stars composing the Milky Way are much nearer to each other than a distance of 21 light years—and this the crowded appearance of the Galaxy would lead us to suppose.

From some counts of stars which I have made on Dr. Roberts's photographs of the Milky Way, I find a total of about 45 millions of stars, or about two or three times the number due to an equal distribution of stars. This agrees with some experiments made by Mr. Gavin J. Burns, who finds that the average brightness of the Milky Way is from two to three times greater than that of the rest of the sky.[1]

Easton thinks that the stellar universe is of "a fairly thick lens shape, filled with stars, which are much more closely congregated near the edges than near the centre of the lens." Professor Newcomb's views are somewhat similar. But this is returning to Sir William Herschel's "disc theory," and it seems doubtful whether such a conclusion is warranted by the evidence. As is well known, this disc theory was abandoned by Herschel himself in his later writings. I have never seen any answer to the argument against the disc theory advanced by me in "The Visible Universe." The argument is as follows: as the thickness of Herschel's supposed disc extends on both sides of the earth beyond the theoretical distance of stars of the 9th magnitude, the stars of this magnitude should be as numerous in the direction of the Galactic poles as in the direction of the Milky Way itself. But this is not the case. Argelander's maps show that 9th magnitude stars are more numerous in the Milky Way than at the northern Galactic pole in the ratio of $2\frac{1}{2}$ to 1. Even the stars visible to the naked eye show a tendency to aggregation on the Milky Way, and Easton finds that the fainter stars of Argelander's catalogue—about $9\frac{1}{2}$ magnitude—"present, in the manner in which they are distributed, a remarkable correspondence with the luminous and obscure spots of the Milky Way." These facts seem to be inconsistent with the disc theory as originally propounded by Herschel. From the evidence quoted above, it seems evident that if the stellar universe is in any way shaped like a "thick lens," there must be a considerable crowding of stars along the edge of the disc; that is, in the direction of the Milky Way.

---

[1] *Astrophysical Journal*, October, 1902.

Struve's modification of the "disc theory," namely, a disc of a certain thickness, but of infinite, or at least indeterminate diameter, seems an improbable hypothesis, and one not in agreement with observed facts. Even on this theory our sidereal system is supposed to be limited in the direction of the Galactic poles. If Struve's theory were accepted, we should be obliged to accept his hypothesis of the extinction of light in the ether; for otherwise the Milky Way would be much brighter than it is. The comparatively feeble gleam of the Galaxy on even the clearest nights should, I think, be sufficient to convince the thoughtful observer that its light is *not* due to a vastly extended stratum of stars. Even Sir John Herschel's reflecting telescope of 18½ inches' aperture (now far surpassed in space-penetrating power by modern telescopes) sufficed in some places to show the component stars of the Milky Way on a *black* background devoid of any nebulous light. With reference to one of his "sweeps," he says, "The northern end of the zone, though pretty rich in *stars*, is yet quite free from brightness of ground. It is as black as a coal," clearly showing that his optical power could—here at least—fairly penetrate through the stellar stratum into the starless void beyond. Modern photographs show the same thing in many parts of the Milky Way. More powerful telescopes and more sensitive plates will probably disclose the existence of many fainter stars, but all the evidence we have at present seems to point to the conclusion that the utmost limit of telescopic vision will soon be reached, and that the most powerful telescopes which man can construct will ultimately show that the stars, even in the richest portions of the Milky Way, are strictly limited in number.

With reference to the clusters and nebulæ, the distance of these objects has not been ascertained; but from the fact that stars, clusters, and nebulæ are mixed up in the Magellanic clouds in a space which is apparently of a nearly globular form, we may conclude that all these diverse objects may coexist in the same region of space, and that, consequently, the nebulæ are not, as a rule, farther from the earth than the faint stars seen in the same direction. Photographs of the Magellanic clouds taken by the Harvard observers, show that these objects are very rich in small stars. Photographs of the large "cloud" show about 300,000 stars. This would give about 300 millions for the whole sky if equally rich. The small cloud seems still richer, as the photographs show about 280,000 stars on an area of about 10°. This would give the enormous total of 1155 millions for the whole sky, and it is perhaps the richest spot in the heavens. Assuming a distance of 3000 light years, I find an average distance between the component stars of the large cloud of about 9½ years, or more than the distance between Sirius and the earth; and for the small cloud an average distance of about five light years. It will be seen that both are considerably less than the average for the whole sky, and show that the stars in the "clouds" are crowded together.

Seeliger estimates that the limits of the Milky Way lie between 500 and 1100 times the distance of Sirius, that is (the distance of Sirius being 8·8 "light years"), between 4400 and 9680 light years. At these distances our sun would be reduced to the magnitudes 15·7 and 17·4 respectively. As most of the stars in the Milky Way are much brighter than this, and as most of them are, according to Kapteyn, smaller than the sun, we may, I think, reasonably reject Seeliger's distances as excessive. Newcomb's estimates are probably much nearer the truth.

CHAPTER XXII

A POSSIBLE CELESTIAL CATASTROPHE

> "The heavens being on fire shall be dissolved, and the elements shall melt with fervent heat."

THE above words are from the third chapter of the Second Epistle General of St. Peter (verse 12). It is a matter of some uncertainty whether this epistle was really written by the apostle Peter. There are no certain traces of it earlier than the third century. Its authenticity was questioned by Origen, and St. Jerome says that many in his time rejected it. The difference in style between the First and Second Epistle is so great that modern critics think it improbable that the Second Epistle was written by St. Peter. But there is "no consensus of opinion against it," and as it is now universally admitted into the canon of Scripture, we may, perhaps, accept it as genuine. However this may be, it seems remarkable that in the great Sanscrit epic poem, the Mahabharata, there is a distinct prediction of the destruction of the world by fire. In that ancient work the following passage occurs:[1] "O king, towards the end of those thousands of years constituting the four *Yugas*, and when the lives of men become so short, a drought occurs extending for many years. And then, O lord of the earth, men and creatures, endued with small strength and vitality, becoming hungry, die by thousands. And then, O lord of men, seven blazing suns, appearing in the firmament, drink up all the waters of the earth that are in rivers and seas. And, O bull of the Bharata race, then also everything of the nature of wood or grass that is wet or dry, is consumed and reduced to ashes. And then, O Bharata, the fire called *Samvartaka*, impelled by the winds, appeareth on the earth that hath already been dried to cinders by the seven suns. And then that fire, penetrating through the earth and making its appearance in the nether regions also, begetteth great terror in the hearts of the gods, the *Dānavas* and *Yakshas*. And, O lord of the earth, consuming the nether regions as also everything upon this earth, that fire destroyeth all things in a moment," etc. This agrees with St. Peter's words, "the elements shall melt with fervent heat, the earth also and the works that are therein shall be burned up." The idea of "seven suns" in the Mahabharata is also in curious agreement with the words of the prophet Isaiah (chap. xxx. ver. 26): "Moreover the light of the moon shall be as the light of the sun, and the light of the sun shall be sevenfold, as the light of seven days, in the day that the Lord bindeth up the breach of His people, and healeth the stroke of their wound." Assuming the truth of these remarkable predictions, let us see how the catastrophe of a general conflagration might be brought about by the operation of natural causes without the intervention of a miracle.

---

[1] From an English translation of the "Vana Parva," by Pratāp Chandra Rāy, C.I.E.; 2nd edition, 1889, p. 561.

Some have supposed that such a catastrophe might possibly be produced by an outburst of the internal fires of the earth. But such an hypothesis—in itself very improbable in a cooling globe like the earth—is directly opposed to St. Peter's words, "the heavens being on fire shall be dissolved," clearly indicating, I think, that the fire is to come from the *outside*. "The heavens," *not the earth*, being on fire is to be the cause of the catastrophe. Others have thought that an outburst in the sun would perhaps produce the conflagration, and this certainly seems much more probable. Were the sun to suddenly blaze out, like the "temporary" stars recorded in the annals of astronomy, and of which we had such a brilliant example in February, 1901, in Perseus, then, of course, the earth would certainly be burnt up, and, at least everything on its surface, would at once be reduced to ashes. But although this is, of course, within the bounds of possibility, such a catastrophe is not, I think, at all probable. There are, to be sure, small outbursts daily taking place in our central luminary, as indicated by the "prominences," or red flames visible round the sun's limb during total eclipses, but these are of comparatively small importance, and not likely at any time to endanger the earth's safety. An outburst on a much larger scale would be necessary to produce anything in the way of a catastrophe, such as would destroy all life on our terrestrial abode. Now, is there any cause which would produce a great outburst of light and heat in the sun? I think we have such a cause in the possible collision of the sun with a dark body in space. The distance of the stars is so great that the collision of the sun with a *star* is a contingency which may be at once dismissed. Such an event, if it ever took place, could not possibly happen for thousands of years to come. To pass over the distance which separates us from even the nearest fixed star would take, at the rate of, say, ten miles a second, about 80,000 years.

The existence of dark bodies in space has been suspected by astronomers. I say suspected, for really we have no *direct* evidence that such bodies exist. The idea seems to have originated in the so-called "dark companion" of the variable star Algol. But we have no evidence that Algol's companion is really a "dark body," that is, a body devoid of all inherent light, like the earth. It is true that the spectroscope shows no sign of a second spectrum, as in some variables of the Algol type, in which both components are of nearly equal brightness. But it has been recently found by Professor Hartmann that "a difference of only about one magnitude would be sufficient to bring the spectrum of the fainter component to almost complete disappearance, and a difference of two magnitudes would make it impossible for even a trace of the fainter spectrum to be visible on the plate."[1] The companion of Algol might therefore be a star of 4½ or 5th magnitude, and neither telescope nor spectroscope would show any trace of its existence. But apart from the above considerations, it seems very probable that many dark bodies do exist in space. In the case of large bodies of this kind, they would have their origin in cooled-down suns. Stars cannot go on shining for ever. They commence their career with a limited amount of potential energy, and this energy is being incessantly dissipated in the form of radiant light and heat. This dissipation of energy clearly cannot go on continually, and in the course of ages it must become exhausted. It is like a man living on his capital. If he receives no interest on it, and goes on spending the money steadily, the day must come, sooner or later, when the capital will disappear, and the man be reduced to bankruptcy. So it is with a sun. It can receive no energy from without, and it is constantly wasting its capital of energy in the radiation of light and heat. It is true that this waste may be apparently compensated for a time by the contraction of the sun's mass due to gravity. But this is only the conversion of potential energy into heat, and eventually the process must cease, as after a time—counted, of course, by ages—the sun's density will become so great that the contraction will cease, owing to the overcrowding of the molecules, no further heat will be produced, and the body will begin to cool down. When this cooling process has sufficiently advanced, the sun will lose its light, and "roll through space, a cold and dark ball." There is evidence to show that in some of the variable stars this permanent waning of light has already commenced, and it seems highly probable that in many cases the cold and dark stage has been actually reached. These dark bodies may indeed be very numerous. We have no means of observing them, as they show no light, and would not be visible, even as faint stars, in the largest telescopes which could ever be constructed.

---

[1] *Astrophysical Journal*, May, 1904.

It is now well known that the sun is moving through space with a considerable velocity, and, of course, carrying with it the earth and all the planets of the solar system. Various estimates of the point towards which the sun is moving have been made, but the most recent and accurate calculations seem to point to a spot near the bright star Vega (α Lyræ). In its flight through space it seems quite within the bounds of possibility that the sun may some day come into collision with a dark body. Should such an event occur, the collision would, of course, produce an enormous amount of heat and light, and St. Peter's prediction would at once be fulfilled. "The heavens" would be "on fire," and the whole surface of the earth and everything on it would be reduced to cinders in a few minutes. It would be like the destruction of St. Pierre on a colossal scale. The world would end

"In unremorseful folds of rolling fire."[1]

But such a catastrophe could not occur without our knowing of the coming disaster months, and perhaps years, beforehand. When the approaching dark body came within a certain distance of the sun, it would begin to shine by reflected light, like the planets. If a very large body, comparable with the sun itself in size, it would first become visible far beyond the confines of the solar system. For some months or years its motion would be very slow, owing to its great distance from the sun. It would probably be first discovered as a telescopic star, not differing in appearance from other stars of the same magnitude in its vicinity. It would then perhaps shine as a star of the 9th magnitude, as any much fainter star would probably be overlooked. Doubtless it would at first be mistaken for a "new" or "temporary" star, or a variable star at its maximum light, but the comparative constancy of its light, and its great parallax, or apparent change of place among the neighbouring stars, would soon show astronomers its true character, and that it was really near the earth compared with the distance of the stars. It might, however, be mistaken for a distant comet, but if coming directly towards the sun, its change of place would be small, and its light examined with the spectroscope would show a solar spectrum, showing that, like the planets, it was shining by reflected sunlight. Further, its distance could be calculated from its parallax, and the result would show that no comet could be visible at such a distance from the sun.

---

[1] Tennyson, "The Holy Grail."

I have made some calculations on the motion of this hypothetical body after it became visible as a star of the 9th magnitude, and therefore easily visible in a telescope of 3 inches aperture. Let us suppose the approaching dark body to have the same mass as the sun and the same density as the earth. Taking the earth's density as four times that of the sun, and the sun's diameter as 866,000 miles, I find that the diameter of the dark body would be about 546,000 miles. Now, taking the diameter of Uranus as 33,000 miles, its stellar magnitude as 5·7, and assuming that the dark body has the same "albedo," or light-reflecting power, as Uranus, I find that the dark body would shine as a star of the 9th magnitude when at a distance from the sun of 8·68 times the distance of Uranus, or about 15,000 millions of miles. Further, assuming that the sun is moving through space at the rate of 11 miles a second (about its probable value), and that the dark body is moving directly towards the sun with the same velocity, we can calculate by the laws of dynamics the time taken by the two bodies to come together, starting with a distance between them of 15,000 millions of miles. The motion for the first few years would be comparatively slow, and, as I have said, the increase in brightness would at first be imperceptible. To reduce the distance to 12,000 millions of miles would, I find, take about 3·4 years. At the end of 6·7 years the distance would be reduced to 9000 millions and in 9·8 years to about 6000 millions of miles. At this distance the brightness would increase to about the 5th magnitude, and it would then be distinctly visible to the naked eye. In about 11·8 years the distance would be reduced to 4000 millions, and in about 14 years the dark body would reach the orbit of Uranus, or rather it would be then at the same distance from us as Uranus, for its path would not intersect the orbit of the planet, as I will show presently. It would then shine as a star of about −0·4 magnitude, or a little brighter than Arcturus, and would, of course, attract general attention. After this its distance would rapidly diminish, and its light quickly increase. After about a year from this time it would reach the distance of Jupiter. Its light would then be greatly increased. It would appear as a star of about −6·5 magnitude, or about 4 magnitudes brighter than Jupiter at its brightest, and about 2 magnitudes brighter than Venus at her greatest brilliancy. It would then be the brightest object in the heavens with the exception of the moon, and would be "the observed of all observers." After this its motion would become very rapid, and in about 51 days it would be at about the same distance from the sun that the earth is. From this point my calculations show that the velocity would be very rapid, and if a direct collision took place, the sun and dark body would meet in a little less than eight days, the velocity of each body being then over 400 miles a second. The effects of such a collision may be easily imagined. Both bodies would be reduced to the gaseous state within an hour, and a stupendous amount of heat would be produced, heat sufficient not only to destroy the earth, but probably most of the planets of the solar system.

If the dark body approached the sun in a straight line, it could not strike the earth itself or any of the planets, for the direction of the sun's motion is inclined to the plane of the earth's orbit at an angle of about 60°. The nearest approach of the body to the earth would depend on the time of year at which its collision with the sun took place. If this occurred about the end of December, the dark body would not approach the earth nearer than the sun's distance; but if the collision took place about June 21, I find that the body would approach the earth within about 80 millions of miles. In this case its attraction on the earth would be greater than that of the sun, and it would probably draw the earth out of its orbit. In either case, when the collision took place the sun's mass would be suddenly doubled, and, according to Professor Young, the earth's orbit "would immediately become an eccentric ellipse, with its aphelion near the point where the earth was when it occurred."[1] But, of course, this would not concern humanity, after the earth and all its inhabitants had been reduced to ashes.

---

[1] "Manual of Astronomy," p. 294.

It is, of course, possible that the dark body would not approach the sun directly in a straight line, but along an elongated ellipse. In this case its path might intersect the earth's orbit, and a direct collision with the earth itself would become possible, although not very probable. But in this case, if it missed striking the earth, it would also miss the sun, and there would be no collision. But the earth's motion in its orbit would be much disturbed by the powerful attraction of the dark body, and it is not easy to determine what the exact result would be. If, however, the body were moving in an ellipse sufficiently elongated to pass inside the earth's orbit, it would probably pass close enough to the sun to produce a great disturbance in that body due to tidal action, and a large amount of extra heat would probably be developed. Should the two bodies merely graze each other, an enormous amount of heat would certainly be produced, quite sufficient to cause the earth's destruction.

The approach of the dark body to the sun would form a magnificent celestial spectacle. When it arrived within the sun's distance from the earth, it would, I find, shine with about the same brightness as the moon when full, but with a smaller diameter, and it would increase rapidly in brightness of surface as it approached the sun. It would then—especially if the approach occurred in the month of June—begin to show phases like the moon, and we should then have the curious spectacle of two moons in the sky, one somewhat smaller than the other!

Instead of a dark body of the mass of the sun, we may suppose one very much smaller, say of the size of Jupiter. In this case, the masses being so unequal, the sun's motion would be much smaller. On the other hand, the dark body would not become visible until it was much nearer to the earth. In the case of a body like Jupiter, say 87,000 miles in diameter, I find that it would become visible as a star of the 9th magnitude at a distance of about $3\frac{1}{2}$ times the distance of Uranus from the sun, or about 6000 millions of miles from the earth. If the diameter of the dark body was the same as that of the earth, it would shine as a star of the 9th magnitude at about the distance of Uranus from the earth, and in this case it would fall into the sun in about 3 years. The amount of heat produced by the collision would, of course, be much smaller than in the case first considered, but it seems very probable that even a body the size of the earth, moving with such a high velocity when it struck the sun, would produce the most disastrous results to the earth. Such a body may possibly be now approaching us. If only the size of the earth, it might easily escape detection until well within the orbit of Uranus, and we might then have only a few months' warning before the final catastrophe occurred. But, it may be asked, is there any star visible at the present time which might be identical with an approaching dark body? Well, all I can say is this, that I have carefully examined the region round Vega with a powerful binocular field-glass, and that at present (April, 1905) there is no star brighter than the 7th magnitude within 5° of Vega, which is not perfectly well known to astronomers. A careful examination with a 3-inch telescope, or, better still, a photograph of the region, would, however, be necessary before a decided opinion could be formd on the subject.

CHAPTER XXIII

RECENT ADVANCES IN STELLAR ASTRONOMY

IN my book "Studies in Astronomy" I gave some account of recent advances in stellar astronomy up to the end of the year 1903. The following are the most remarkable discoveries and advances which have been made since that date.

Mr. W. F. Very has come to the conclusion that a parallax of 0·05 second may be definitely adopted for Nova Persei. This would imply a light journey of about 65 years. This parallax would "inferentially represent the distance of the Milky Way in its vicinity." The only objection which can be urged against this result is that "it gives much smaller values for the dimensions of the Galaxy than appears probable from other considerations." But possibly portions, at least, of the Milky Way may be nearer to us than is generally supposed. The great brilliancy which Nova Persei attained seems to suggest that its distance was probably not greater than some of the stars whose parallax has been determined. Mr. Very points out that if we assume a parallax of only 0·01 second, as given by Aitken and Chase, the velocity of the radiation which lit up the surrounding nebula "would be 1,500,000 kilometres a second, or greater than that of light, but of such velocities we have no knowledge."[1] A parallax of 0·05 second would make this velocity 300,000 kilometres a second, or about the same as that of light.

A new orbit of Sirius has been completed by M. O. Lohse. He finds a period of 50·381 years, with a semi-axis major of 7·427 seconds, and an eccentricity of 0·598. It was measured by Professor Barnard in October, 1903, and he found 115·06″ : 6·33″. The companion is now within reach of medium-sized telescopes.

From observations of the colour of 53 variable stars of short and long period, Mr. Paul S. Yendell comes to the following conclusions. From 7 short-period variables he finds "no suggestion of any relation between colour and length of period among these stars." He finds a mean coloration of only 0·8 (on a scale of 0 to 10); 7 "intermediate" stars, with periods of 46 to 165 days, show a marked progression in the lengths of their periods, corresponding to that in their observed colours; 38 long-period stars show a marked correspondence "between depth of colour and length of period," which confirms Chandler's conclusion, "The redder the star, the longer the period." "From 6·8 of colour scale upwards, the stars of irregular variation become relatively numerous"; the reddest star, R S Cygni, being of this type of variation.[2]

Professor H. C. Wilson finds on photographs taken with a 6-inch camera large patches of nebulosity in some of Sir William Herschel's nebulous regions where Dr. Roberts found none, and he adds that Dr. Roberts's failure "leads us rather to believe that

---

[1] *Astrophysical Journal*, March, 1904.

[2] *Astronomical Journal*, No. 564, June 20, 1904.

Dr. Roberts's work was not done under the most favourable conditions, and that, therefore, there is hope that under better conditions more of these regions given by Herschel may be proved by photographs to be nebulous." With reference to the Pleiades and Orion regions, he says that Herschel's words are "abundantly justified."[1]

From spectroscopic observations of the famous binary star α Centauri (the nearest of the fixed stars), Messrs. Palmer and Wright find a difference in the radial velocities of the components of about 5 kilometres a second. On the assumption that this difference is due to relative orbital velocity, they find by the formulæ of Lehmann Filhés, and the elements of the orbit found by Roberts, a parallax of 0·76 second. This is in good argument with the parallax of 0·75 second found by Sir David Gill. A parallax of 0·76 second gives for the combined mass of the system 1·9 times the mass of the sun.

Professor Simon Newcomb finds that the main stream of the Milky Way "is not on the whole a great circle, for the mean latitude obtained is −1·74°, showing a small but well-marked displacement of our system from the central plane towards Coma Berenices, where the north Galactic pole is situated."[2] In an article on "The Extent of the Visible Universe," in *Harper's Monthly Magazine* for October, 1904, Professor Newcomb says, "Speaking roughly, we have reason, from the data so far available, to believe that the stars of the Milky Way are situated at a distance between 100,000,000 and 200,000,000 times the distance of the sun. At distances less than this it seems likely that the stars are distributed through space with some approach to uniformity. We may state as a general conclusion, indicated by several methods of making the estimate, that nearly all the stars which we can see with our telescopes are contained within a sphere not likely to be much more than 200,000,000 times the distance of the sun." With reference to the possible extinction of light in the ether, he thinks there is none, and that probably there is little or no extinction due to dark bodies. He says, "We may say with certainty that dark stars are not so numerous as to cut off any important part of the light from the stars of the Milky Way, because if they did the latter would not be so clearly seen as it is. Since we have reason to believe that the Milky Way comprises the more distant stars of our system, we may feel fairly confident that not much light can be cut off by dark bodies from the most distant regions to which our telescope can penetrate. Up to this distance we see the stars just as they are." These views support the opinions advocated by the present writer for many years past.

---

[1] *Popular Astronomy*, June and July, 1904.

[2] *Nature*, July 28, 1904.

Dr. See says that, according to Stockwell, the maximum and minimum values of the constant of precession are 52·664080 seconds and 48·212398 seconds. "Stockwell's mean value, 50·438239 seconds, gives 25694·8 years as the total period of the precession, and this appears to be comparatively near the truth."[1]

The short-period variable W. (γ') Sagittarii has been found at the Lick Observatory to be a spectroscopic binary. The period is nearly the same as

[1] *Astronomische Nachrichten*, No. 3966.

that of the variation, but there seems to be no eclipse as in the case of Algol. The elements of the orbit are similar to those of η Aquilæ and δ Cephei.[1] The short-period variable S. Sagittæ (discovered by the present writer in 1885) has also been found to be a spectroscopic binary with a wide range of radial velocity. The curve is similar to those of η Aquilæ and W. Sagittarii.[1] Mr. V. M. Slipher finds that the bright star γ Geminorum is a spectroscopic binary with a period (about $3\frac{1}{2}$ years) comparable in length with that of δ Equulei (5·7 years). The orbit is "quite eccentric," for the change from maximum to minimum velocity takes place in much less time than the change from minimum to maximum.[2] Mr. Adams has computed an orbit for the spectroscopic binary ζ Tauri, and finds a period of 138 days, with an eccentricity of the orbit of 0·180. "No trace of the spectrum of the second component has been found" on any of the photographic plates yet secured. Mr. Heber D. Curtis has computed an orbit for the spectroscopic binary star ι Pegasi. He finds a period of 10·21312 days with a nearly circular orbit. The range of velocity is from +43·7 kilometres to −52·1 kilometres a second. There is "no evidence of a second spectrum."[3] If we suppose that the plane of the orbit passes through the earth, the distance between the components would be about 4 millions of miles. But as the star does not seem to be an Algol variable, the orbital plane is probably inclined to the line of sight. In this case the distance would be greater. For an angle of 60° with the line of sight, the distance between the components would be about 8 millions of miles. The high velocity and short-period indicate that they are comparatively close. Professor Vogel contests the validity of Tickhoff's conclusion that β Aurigæ is quadruple. Vogel finds a period of $3^d\ 23^h\ 2^m\ 16^s \pm 5^s$ with a nearly circular orbit.[1] Professor J. Hartmann has computed an orbit for the spectroscopic binary star δ Orionis. He finds a period of $5^d\ 17^h\ 34^m\ 48^s \pm 17^s$. The system is receding from the earth with a velocity of about 14·3 miles a second. The mass is probably greater than the sun's mass, and "probably of the order of from 5 to 10 times the solar mass."[2] The star has long been suspected of variable light, and Auwers found a period of 16·08 days. If of the Algol type, Hartmann says that the dates of minimum light may be computed from the formula 1902, February 14·02 + nP. Observations made specially by the present writer to detect this supposed variation have proved without result. The companion is comparatively dark, but the components are probably of nearly equal mass. With reference to the invisibility of the spectrum of the companion, Hartmann says, "A difference of about one magnitude would be sufficient to bring the spectrum of the fainter component to almost complete disappearance, and a difference of two magnitudes would make it impossible for even a trace of the faintest spectrum to be visible on the plate. The slight difference of magnitude necessary for the extinction of the fainter spectrum explains the fact that among the numerous spectroscopic binaries so far discovered, there are very few which show the lines of the second component in the spectrum." This shows that the companion of Algol is not necessarily a "dark body," as is usually stated. It may be a star of, say, the 5th magnitude, without the spectroscope showing any sign of its existence.

---

[1] *Publications of the Astronomical Society of the Pacific*, December 10, 1904.

[2] *Astrophysical Journal*, July, 1905.

[3] *Ibid.*, April, 1904.

---

[1] *Astronomische Nachrichten*, No. 3944. See "Studies in Astronomy," p. 291.

[2] *Astrophysical Journal*, May, 1904.

For the binary star γ Coronæ Borealis, Dr. Doberck has computed a period of 79·63 years, with a semi-axis major of 0·598 second.[1] From this it follows that the "relative brilliancy" of the star is about 24 times that of ξ Ursæ Majoris (taken as a standard). Its spectrum is of the Sirian type; that of ξ Ursæ being of the solar type. For the star ξ Scorpii, Mr. R. G. Aitken finds a period of 44½ years, with a semi-axis major of 0·701 second, and an eccentricity of 0·767. He finds that Dr. See's orbit is now in error to the extent of +100·9° in position angle, and "instead of being nearly circular, the orbit is highly eccentric."[2] Aitken's orbit gives a "relative brilliancy" of 6·53. The spectrum is F 8 G (Pickering).

From a plate taken of the great cluster in Hercules (Messier 13) at the Yerkes Observatory on August 15, 1900, Mr. W. E. Plummer finds that the number of stars in the cluster brighter than the 15th magnitude "does not greatly exceed 2000.[3] According to Perrine, about one-third of the total number of stars in the globular clusters lie between the 11th

[1] *Nature*, August 24, 1905.

[2] *Lick Observatory Bulletin*, No. 80.

[3] *Monthly Notices*, R.A.S., June, 1905.

and 13th magnitudes, while almost all the remainder are very faint, about 16th magnitude. He says, "The appearance is that of two layers, one of bright stars superposed upon another of very faint stars; but few of 14 to 15½ magnitude are found in the cluster. This fact may be due either to an actual difference in the size of the stars, or to a difference in constitution or physical condition. The first appears more probable." Perrine says, "In this connection attention may be called to the relation which has been supposed to exist between the nebulæ and star clusters. The belief has been gaining way, since photography has shown the real structure of so many of these objects, that they are but different stages in the process of evolution; that a star cluster has been formed by the condensation of the matter in a nebula. A study of the nebulæ observed with the Crossley reflector shows that a large proportion are spiral, and that practically all the spirals are lenticular or disc-shaped. Many of them are relatively very thin. Now, if the globular clusters are really spherical, how could they have originated from a disc-shaped nebula?"

Perrine now estimates the probable number of nebulæ within reach of the Crossley reflector to be about 500,000, instead of 120,000 estimated by the late Professor Keeler. He thinks that with more sensitive plates and longer exposures this number "will ultimately be found to exceed a million." These small nebulæ seem to be distributed over the whole heavens with some approach to uniformity.

A series of photographs of Eros taken with the Crossley reflector gives for the solar parallax $8{\cdot}788'' \pm 0{\cdot}008''$ (Perrine).

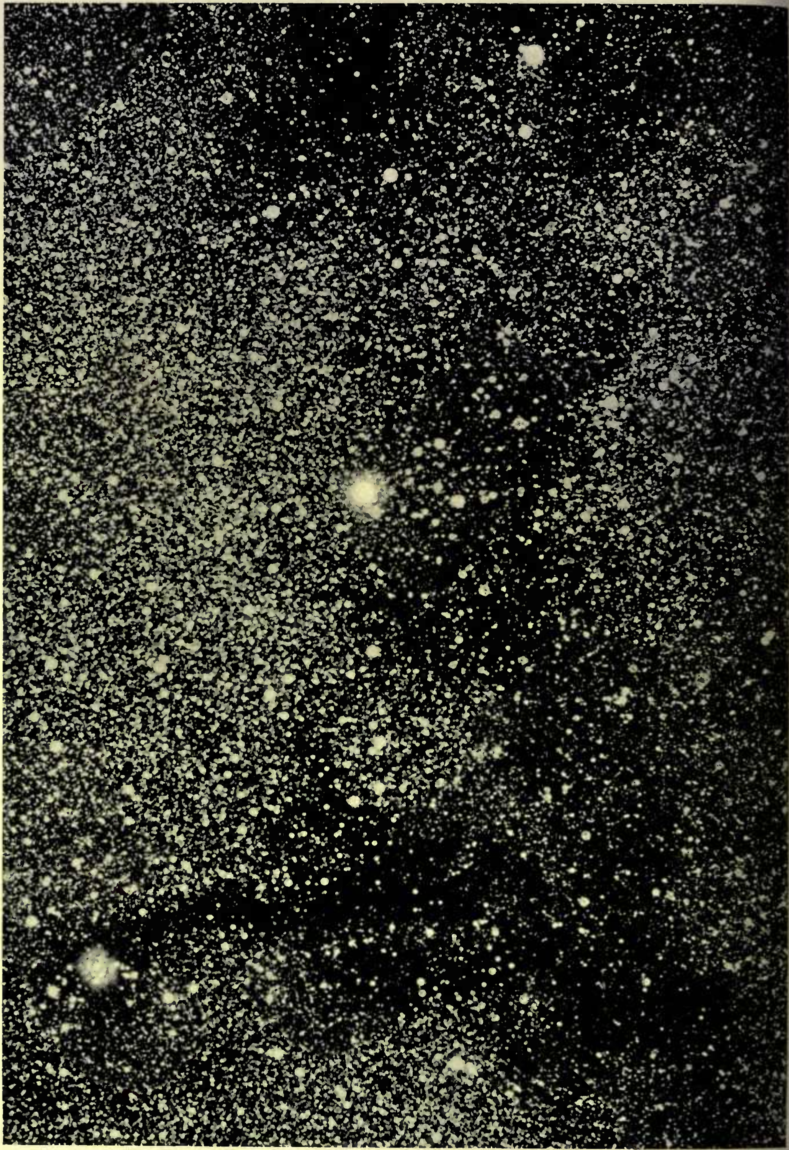

PLATE 4.—MILKY WAY AND NEBULA NEAR π^2 CYGNI.

From original Photograph by Dr. Max Wolf, Heidelberg. Exposure 4 hours (16-inch telescope).

According to Professor Perrine, observations at the Lick Observatory show that the spectrum of *novæ*, or new stars, eventually becomes "continuous without bright lines." The spectrum of Nova Cygni has—according to Palmer—already reached this stage, and that of Nova Persei is evidently approaching it. Perrine thinks that the whole cycle of changes, from the spectrum characteristic of new stars when at their greatest brightness, through the nebular spectrum, on to a continuous spectrum, "occupy but a few years, even in the case of so great an outburst as that of Nova Persei."[1] On July 30, 1903, Nova Persei was estimated 11½ or 12th magnitude at the Lick Observatory, so this famous star seems to be still slowly fading.[2]

Dr. Max Wolf has photographed an interesting nebula in the constellation Cygnus, which is very curiously placed in a dark vacuity in the Milky Way. It lies about 2° south-east of the 4th magnitude star π^2 Cygni. Wolf says, "The nebula is somewhat round, and is about 10 minutes in diameter. It is of a very complicated structure, somewhat resembling the trifid nebula in *Sagittarius.* It is placed centrally in a very fine lacuna, void of faint stars, which surrounds the luminous cloud like a trench. The most striking feature with regard to this object is that the star-void halo encircling the nebula forms the end of a long channel, running eastward from the western nebulous clouds and their lacunæ to a length of more than two degrees." Dr. Wolf suggests the question, "Is there a dark mass following the path of the nebula, absorbing the light of the fainter stars? We are far from knowing enough to settle these questions; but one thing we learn anew from this interesting nebula, and in a very illustrative manner—*that the nebula is geometrically encircled by a ring which is void of faint stars, and that this lacuna is the end of a long starless hole.*"[1] (The italics are Wolf's). He says further, "Similar relations seem to exist for all extended nebulæ." Among these he mentions Messier 8 and 20; the nebulæ near γ Scuti, ρ Ophiuchi, δ Ophiuchi, Antares, ν Scorpii, η Carinæ, S (15) Monocerotis, ξ Persei, β Cassiopeiæ, and γ Cygni. The nebula near π^2 Cygni described above was afterwards photographed by Mr. W. S. Franks with the 20-inch reflector of the late Dr. Roberts, and his photograph fully confirms Dr. Wolf's result. Mr. Franks says, "I have often noticed the curious thinning out of stars in the immediate vicinity of nebulæ, and undoubtedly there must be some physical cause to account for the fact, of which Sir W. Herschel was well aware. Is it possible that some of these objects are surrounded by *dark* and relatively cool nebulous matter, which, viewed in its greatest darkness round the edge, is sufficient to absorb and obliterate small stars behind it? We have no grounds for assuming that the nebulæ generally are more distant than the stars; indeed, from their vast apparent size, they may be much nearer. Considering, too, how few of the stars show any sensible parallax, it may be that some of the nebulæ, when they are seriously attacked, will yield positive results. The long barren channel preceding

---

[1] *Astrophysical Journal*, January, 1904, p. 83.

[2] *Ibid.*, p. 81.

---

[1] *Monthly Notices*, R.A.S., vol. lxiv., No. 9, Supplementary Number.

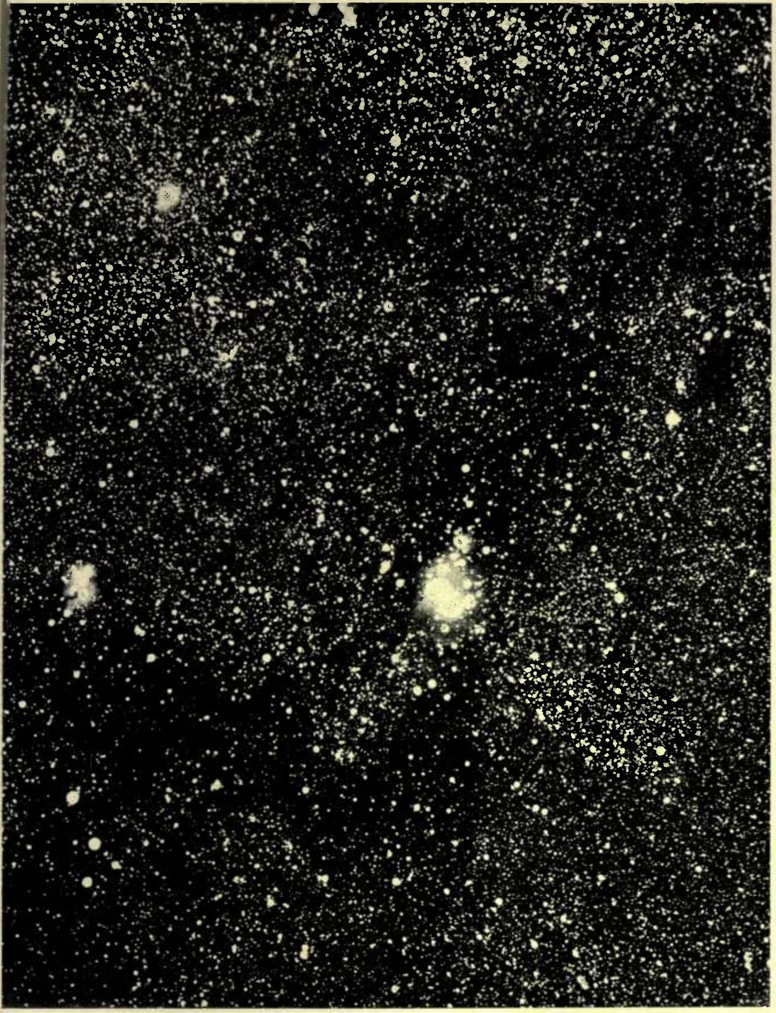

PLATE 5.—NEBULOSITY ROUND THE STAR 15 MONOCEROTIS.

From a Photograph by Professor E. E. Barnard, Yerkes Observatory.

this detached nebula is a very curious feature, and offers an inviting field for speculation."[1]

From measures made at the Yerkes Observatory by Messrs. Adams and Frost with the great 40-inch telescope of the velocity in the line of sight of twenty stars of the "Orion type" of spectrum, they find the following results. The stars examined vary in magnitude from Rigel (0·3) to 102 Herculis (4·5). The velocities found range from + 32·6 kilometres (20·2 miles) in the case of β Canis Majoris, to −26·3 kilometres (16·25 miles) (ε Delphini). The results show clearly the direction of the sun's motion in space, but are, of course, too few in number to determine accurately either the position of the "apex" or the velocity of the solar motion. Assuming, however, Professor Newcomb's position of the "apex" (R.A. 277·5° ; Dec. = + 35°), and Campbell's solar velocity of 19·9 kilometres per second, they find a mean velocity for the 20 stars of only 7·0 kilometres (4·34 miles). Omitting γ Corvi, which has an exceptional proper motion of 0·162 second, the mean proper motion of the others is only 0·015 second. Considering the brightness of the stars examined, this is very small, "much smaller than for solar stars of corresponding brightness, and indicates that the stars of the *Orion* type are as a class very remote." Messrs. Adam and Frost think that these Orion type stars "seem unquestionably to occupy a position very early in the scale of stellar evolution. Their chemical constitution is simple, the chief elements showing lines being hydrogen, helium, oxygen, silicon, nitrogen, and magnesium. The presence of helium is the principal characteristic of the type, whence they are frequently called helium stars." In those stars of the type which are probably the earliest in order of development (such as κ Draconis, ι and λ Orionis), there are no lines visible in the spectrum except those of "hydrogen and the stronger helium lines, and these are faint, and extremely broad and diffuse." In the stars next in order these lines are stronger, narrower, and better defined. In the spectra of those stars further developed (ι Herculis and Rigel) the lines are well defined with traces of silicon. Faint metallic lines also begin to appear, showing a connection with subsequent types. Some, however, of the Orion stars show oxygen and nitrogen lines, and the order in which these should be placed with reference to the others is not clear. The observers, however, think that the relationship between the two groups is "one of parallelism rather than succession."[1]

---

[1] *Monthly Notices*, R.A.S., December, 1904.

A careful investigation of the spectra of the red stars of Secchi's fourth type has also been made at the Yerkes Observatory by Professor Hale, Ellerman, and Parkhurst, and they arrived at the following conclusions. The spectra contain a large number of bright and dark lines, in addition to the flutings of cyanogen and the flutings of the "swan spectrum." The velocity of 8 of these fourth-type stars range from + 5 kilometres to − 28 kilometres. Measurements of 307 dark lines indicate the presence of the following elements: carbon (as cyanogen and in the elementary or combined state corresponding to the swan spectrum), hydrogen, vanadium, calcium, magnesium, sodium, iron, chromium, titanium, nickel, manganese, and possibly two or three others. "The carbon and metallic vapours are very dense, and lie immediately above the photosphere. Above these dense vapours of the reversing layer rise other vapours or gases, represented in the spectra by bright lines." About 200 of these bright lines were observed, but could not be identified with certainty with those of any known gases. A few of them may possibly correspond with bright lines in the Wolf-Rayet stars. The appearance of the dark lines suggests, but does not prove, that the temperature of the reversing layer in these stars is lower than in the case of the sun. The appearance of some of these also suggests the presence of numerous sun-spots. About 20 per cent. of the fourth-type stars are variable. This is a larger proportion than in the case of the third-type stars. "The condensation of fourth-type stars in and near the Milky Way is very marked. Stars of the third and fourth types resemble each other in colour, tendency to variability, spectra, possible presence of sun-spots, physical condition, and probable relationship to solar stars. They should therefore be classed together, as co-ordinate branches leading back to stars like the sun. Variations in the relative intensities of certain titanium lines indicate that fourth-type stars are probably very widely separated from Wolf-Rayet stars in point of development. Fourth-type stars probably develop from stars like the sun through loss of heat by radiation."[1] The observers consider that these fourth-type stars "represent the last stage of stellar development."

---

[1] *Publications of the Yerkes Observatory*, vol. ii.

Dr. Doberck has computed a new set of elements for the orbit of the satellite of Sirius. He finds a period of 49·49 years, with a semi-axis major of 7·513 seconds, and an eccentricity of 0·5871. This does not differ much from previous determinations. With Gill's parallax of 0·37 second, Doberck's orbit gives a combined mass equal to 3·434 times the sun's mass, the mass of the satellite being about equal to the sun's mass.

---

[1] *Publications of the Yerkes Observatory*, vol. ii. p. 135.

In the nebulous region near ρ Ophiuchi, 72 new variable stars have been discovered at Harvard Observatory. Among these the greatest variation of light amounts to 4·1 magnitudes. All these are faint stars, only 10·5 to 14·2 magnitude at maximum. In the globular cluster Messier 4, 33 variable stars were discovered. Greatest variation 1·6 magnitude. These are also faint, from 10·5 to 13·1 magnitude at maximum. In the "trifid nebula" (Messier 20), 16 variables were found, the largest variation being 4 magnitudes. The stars are mostly faint, from 9·5 to 14 magnitude at maximum.[1]

Professor E. C. Pickering finds that the spectrum of the star λ Cephei (5·6 magnitude) is peculiar, and identical with that of ζ Puppis.[2] This is a very rare spectrum, and shows some hydrogen lines which have not yet been seen in laboratory experiments.

Dr. J. Möller finds the following results for the colours of stars down to magnitude 3·4, estimated on a scale of 1 to 9, 1 being nearly white, and 9 full red: Antares, 7·5 to 7·8; Betelgeuse, 7·4 to 7·6; ζ Aræ, 7·4 to 7·6; Aldebaran, 7·2; ζ Cephei, 7·0; ε Crucis, 7·0; δ Virginis, 7·0.[3]

From an investigation by Messrs. F. W. Dyson, F.R.S., and W. G. Thackeray, of the Greenwich

---

[1] *Astronomische Nachrichten*, No. 3994.

[2] *Ibid.*, No. 3995.

[3] *Ibid.*, No. 3980.

Observatory, based on the proper motions of a large number of stars of different magnitudes, derived from a comparison of Groombridge's Catalogue (1810) with modern Greenwich observations, they find that "the most probable value of the position of the apex of the sun's motion derived from the discussion is R.A. 275°, or $18^h\ 20^m$, declination +37°." This point lies between Vega and κ Lyræ—a little nearer to κ. This result is in good agreement with the results found by Boss (1890) and Newcomb (1899).

In *Popular Astronomy* for May, 1905, Mr. S. M. Hadley gives formula for finding the relative masses of the components of binary stars from measures of a third star near the binary. From measures of σ Coronæ Borealis (period 370·0 years, See) and a third star which has varied in distance (owing to the proper motion of the binary system) from about 44 seconds to 62 seconds, he finds that the masses of the components are in the ratio of 1 : 1·08, or about equal in mass. The magnitudes of the components are 6 and 7 (yellow and bluish), or the primary is about $2\frac{1}{2}$ times brighter than the companion. For β Delphini the ratio of the masses has not yet been determined. In this case the components are 4 and 6 magnitudes, or the primary star is about 6·31 times brighter than the companion.

Professor H. C. Wilson (U.S.A.) finds that on a photograph taken by him of the Pleiades region with a 6-inch Brashear star camera, this region (one of those described by the late Dr. Roberts as containing no nebulosity) "is really filled with nebulous matter covering an area equal to that allotted by Herschel to the whole of the nebulosities in his 52 regions."

From measures of photographic plates, H. N. Russell, Ph.D., finds a parallax of 0·074 second for the star γ Virginis, and 0·344 second for the star Lalande 21,185.[1] The latter star has long been known as one of the nearest stars in the heavens. Its magnitude is about 7½. If our sun were removed to the distance indicated by the above parallax, it would, I find, shine as a star of about 2·4 magnitude. The sun is therefore about 100 times brighter than the star, and Lalande 21,185 must be either a comparatively small body, or else the luminosity of its surface must be considerably less than that of the sun. It has a very large proper motion of 4·75 seconds (one of the largest known), and this, combined with the above parallax, would imply a motion of 40·6 miles per second at right angles to the line of sight. As it may have some motion *in* the line of sight, its actual velocity is probably greater than this.

In the *Astronomische Nachrichten*, No. 3946, M. Adalbert Prey, of Vienna, gives the results of an investigation of the ratio of the masses of the components of the binary star 70 Ophiuchi, using 33 meridian observations of the principal component. He obtains the remarkable result that the mass of the companion is four times as great as that of the bright star! Using Schur's parallax of 0·16 second, he finds the masses of the two stars to be 0·32 and 1·28 times the sun's mass.

No less than 910 variable stars have been discovered in the smaller Magellanic cloud on photographic plates taken at Arequipa by the Harvard observers. "It is estimated that the number of stars photographed in the small Magellanic cloud and adjacent clusters is about 280,000, of which 910, or 1 in 308, is variable. In the surrounding region about 40,000 stars appear on the best negatives, of which 12, or only 1 in 33,000, have been found to be variable, although all have been examined with great care."

---

[1] *Monthly Notices*, R.A.S., June, 1905.

Mr. Lampland, of Mr. Percival Lowell's Observatory, finds that the faintest stars shown on charts made at the Lick Observatory with the 36-inch telescope are perfectly visible with the 24-inch telescope of the Lowell Observatory.[1]

Professor C. L. Doolittle finds from 15,000 observations, extending over a period of 7 years—1896 to 1903—at the Flower Observatory, and from similar work at the Sayre Observatory, a value for the constant of aberration of 20·540 seconds.[2] The corresponding value of the sun's parallax would be 8·76 seconds. From measures of lines in the spectrum of Arcturus, Herr K. Küstner finds a value of the solar parallax of 8·844 seconds. All the values of the sun's parallax found in recent years seem to cluster round a mean value of 8·80 seconds, which is the value now usually adopted by astronomers.

A new star in Aquila was discovered in August, 1905, on plates taken at Harvard. Its magnitude was about 7. Professor Max Wolf found it 9·3 on September 4; Dr. Guthnick estimated it 10·2 on September 4, and of a yellowish colour; and Professor Hartwig 10m. on September 5. Its position for 1905·0 is R.A. $18^h\ 57^m\ 5^s$, S. 4° 34·8′, or a little north-west of the star λ Aquilæ. This will be known as Nova Aquilæ, No. 2, the first *nova* in this constellation having been discovered in July, 1900; but it was visible as 7m. on a plate taken on April 21, 1899.[1]

---

[1] *Popular Astronomy*, August and September, 1905.

[2] *Astronomical Journal*, July, 1905.

In a paper by J. Halm in the *Proceedings of the Royal Society of Edinburgh*, he advances further arguments in favour of Seeliger's theory that the phenomenon of a temporary star is due to "the collision of a dark solid body with matter of nebulous consistency." He says that after the collision occurs a central photospheric radiation would be formed, and this would be surrounded by an atmosphere showing bright lines in its spectrum. All the particles of this atmosphere will be moving radially outwards from the star's centre. All the rays leaving the photosphere from the hemisphere turned towards the earth will thus have to pass through the absorbing atmosphere, and will show a spectrum with dark lines. Bright lines will also be visible formed by the atmosphere itself. As all the particles of the absorbing atmosphere are moving with high velocities towards the observer, the dark lines will be displaced towards the violet end of the spectrum. This displacement of the dark lines towards the violet has been the characteristic feature of all the temporary stars hitherto observed with the spectroscope. Other facts in the history of new stars are also satisfactorily explained by this hypothesis.

A remarkable variable star of the Algol type has been discovered on photographic plates taken at the Harvard Observatory. It varies from 7·14 magnitude to about the 11th magnitude (photographic), with a period of 2·77 days. The variation is "much greater than that of any other Algol star as yet discovered," the light at maximum being about 35 times the light at minimum. Its position for 1900 is R.A. $3^h\ 57^m\ 45^s$, N. 37° 51′. It lies about 50′ north-west of 41 Tauri, and about 1° 10′ south-west of ψ Tauri. At maximum it may be seen with a good binocular, but at minimum it would be quite invisible with such an instrument. It may be followed, however, through all its phases with a 4-inch telescope. Its spectrum, like that of all the Algol variables, is of the first type.

---

[1] *Nature*, September 14 and 21, 1905.

Mr. J. Miller Barr, of Ontario, Canada, finds that the star 32 Cassiopeiæ is variable to the extent of 0·4 magnitude with the remarkably short period of $7^h\ 59^m$. The variation (about 5·2 to 5·6 magnitude) has been confirmed by Mr. Paul S. Yendell, of Boston (U.S.A.), the well-known variable star observer.[1] The colour is yellowish, and the spectrum of the Sirian type (A). Another still more remarkable variable has also been detected by Mr. Barr. This is D.M. + 30°,42, and lies about 3½° north-east of the bright star α Andromedæ. Mr. Barr finds that it is variable to the extent of 0·4 magnitude, with the phenomenally short period of $2^h\ 41{\cdot}1^m$, which would be the shortest period known. He thinks, however, that it may be necessary to double this period, making it $5^h\ 22^m$. This would still be the shortest period known with one exception, W. Ursæ Majoris, which has a period of only $4^h\ 0^m\ 13^s$. The new variable is of a yellowish colour, and its spectrum of the Sirian type. The variation is about from 5·5 to 5·9 magnitude.

---

[1] The variation is, however, disputed by J. A. Parkhurst and F. C. Jordan, from photographic measures (*Astrophysical Journal*, January, 1906).

With reference to the distribution of stars with different types of spectra, Professor Pickering finds that the stars of the first or Sirian type, "although frequent in all parts of the sky, predominate along a certain plane, thus forming the Milky Way." The stars of Class B. (the "Orion" or "helium" stars) "are nearly all in the Milky Way. Only four per cent. are in the half of the sky north and south of it." The stars of the second and third type "show no concentration in the Milky Way, but are, in general, uniformly distributed in all parts of the sky."[1]

Professor Ceraski has recently made some observations with a view to determine the value of the sun's stellar magnitude. He compared the light of Venus with a reflected image of the sun during the daytime, and at night compared Venus with the stars Polaris, Procyon, and Sirius. Taking the photometric magnitude of Polaris as 2·15, that of Procyon 0·56, and Sirius −1·09, his results give for the sun's stellar magnitude −26·51, −26·66, and −26·67, and a weighted mean value of −26·59. Instead of using the minus sign, he calls the sun's stellar magnitude 26·59 *super magnitude*.[2] The magnitude of Sirius found at Harvard, viz. −1·58, would, however, give a somewhat higher value than that found by Ceraski.

M. H. E. Lau, of Copenhagen, found the star β Herculis below its normal brightness in August and September, 1905, and as it is a spectroscopic binary with a period of about 410½ days, he suggests that it may be a variable of the Algol type. Variation was suspected by Sir William Herschel.

---

[1] *Annals of Harvard College*, vol. lvi., No. 1.

[2] *Astronomische Nachrichten*, No. 4065.

From a comparison of the spectrum of sun-spots, observed at Princeton (U.S.A.), with that of fourth-type stars recorded at the Lick Observatory, Mr. Walter M. Mitchell finds that carbon is apparently absent from sun-spots, while its presence in fourth-type stars is strongly indicated by the absorption bands in their spectrum. The magnesium lines are prominent in the fourth-type spectrum, but are of small importance in the spot spectrum, no observation of these lines being recorded at Princeton. "In contrast to this is the behaviour of the manganese lines, which are of relatively great importance in the spot spectrum, and are apparently of minor importance in the spectra of the fourth-type stars." He concludes that "it seems improbable that spots, such as exist on the sun, constitute a characteristic feature of fourth-type stars."[1] With reference to third-type stars, a comparison made by Adams and Hale between the spectrum of α Orionis (Betelgeuse)—taken with the Snow telescope—and the sun-spot spectrum "affords strong evidence of the general agreement between the spectrum of α Orionis and that of sun-spots."[2]

The fainter component of the well-known binary star Castor was found some years ago to be a spectroscopic binary with a period of 2·93 days. Professor Heber D. Curtis, of the Lick Observatory, confirms this, and finds that the brighter component is also a spectroscopic binary with a period of about 9·2 days, the whole forming a remarkable quaternary system. The spectroscopic measures indicate the remarkable result that the mass of the fainter component is six times the mass of the brighter component.

---

[1] *Astrophysical Journal*, April, 1906.

[2] *Ibid.*, June, 1906.

In a paper read before the British Astronomical Association in June, 1906, Mr. Gavin J. Burns says that the luminosity of the sky on a moonless night is not wholly due to starlight, for if this were so, the light should diminish near the horizon, as the lucid stars do. "As a matter of fact, the exact opposite is the case." The light also varies in brightness. This I can fully confirm from my own observations. Sometimes the night sky is comparatively dark, while at others there is a sort of phosphorescent glow over the whole sky.

From meridian observations of the binary star 85 Pegasi, and measures made from a third star of the 9th magnitude, "which seems to be fixed," Messrs. W. Bowyer and H. H. Furner, of Greenwich Observatory, find that the mass of the bright star is to the mass of the companion as 3 to 8, that is, the companion has nearly three times the mass of the primary.[1] As the magnitude of the primary star is 6, and that of the companion 10, this is a very remarkable result, the apparent brightness being in the ratio of 100 to 1.

From photographs taken at the Cambridge Observatory, Messrs. Arthur E. Hinks and Henry Norris Russell find a parallax for Mira Ceti of 0·136 second. With reference to this result, which is of great interest, Mr. Russell says, "If the other long-period variables resemble it, and their maximum rather than their minimum light is comparable with the sun's, the brighter ones must have easily measurable parallaxes, and it would pay to observe them.

---

[1] *Monthly Notices*, R.A.S., May, 1906.

Campbell and Stebbins find that the radial velocity of Mira is constant and equal to + 63 km. per second. As its cross velocity is only 8 km., it is moving almost directly away from us—in a direction making an angle of only 7° with the line of sight. If the present value of the parallax is correct, it follows that Mira was nearest to the sun about 110,000 years ago. It was then in Ursa Major, and had a parallax of 1·1 second, and a proper motion of 15 seconds per annum. If its intrinsic brightness varied between the same limits as at present, it was of the 5th magnitude at minimum, and at maximum was as bright as Sirius."[1] The star passed through an unusually bright maximum in December, 1906, when it was fully 2nd magnitude, or perhaps slightly brighter. It has not been so bright at maximum for over sixty years.

Aitken finds that the binary star 13 Ceti has the short period of 7·42 years. This is shorter "than any other known visual binary except δ Equulei"[2] (5·7 years).

---

[1] *Monthly Notices*, R.A.S.; December, 1906.

[2] *Publications of the Astronomical Society of the Pacific*, February 10, 1907.

CHAPTER XXIV

THE NEW COSMOGONY

In Laplace's nebular hypothesis, the original mass from which the solar system is supposed to have been evolved was considered to consist of gaseous material filling a space of spheroidal form and extending to the orbit of Neptune, or somewhat beyond it. The whole gaseous mass was supposed to be in hydrodynamical equilibrium, and rotating in a period equal to the period of revolution of the present farthest planet. We might also assume that the original mass consisted of a swarm of meteorites, for Professor G. H. Darwin has shown that such a swarm would have nearly the properties of a gas. On either assumption the mass would contract by its own gravitation, and the angular velocity gradually increasing, the centrifugal force would in time flatten the spheroidal mass at the poles. From this flattened spheroid Laplace thought that rings would be detached at certain intervals, and that these rings consolidating, would eventually form the planets and satellites as we now see them.

It has been shown, however, by Professor F. R. Moulton, that the matter detached from the rotating gaseous spheroid would be "shed continually," and that no separate rings could be formed. This would occur whether we consider the original mass to have been gaseous or composed of meteorites. But supposing the rings to have been, by some miracle, detached from the parent mass, we should expect to find that the plane of Mercury's orbit would deviate less than the other planets from the average plane of the planetary system; also that the orbits of the "terrestrial planets," Mercury, Venus, the Earth, and Mars, would be less eccentric, that is, more circular, than those of the outer planets. But the known facts concerning Mercury's orbit are quite opposed to these conclusions. The inclination of its orbit to the plane of the ecliptic (7°) is greater than any of the large planets, and the eccentricity of its orbit (0·20) is only exceeded by that of some of the minor planets revolving between Mars and Jupiter. Further, Moulton shows that the distribution of masses among the planets of the solar system indicates that the original nebulous mass must have been very heterogeneous, and not homogeneous, as Laplace's theory postulates.[1]

There are numerous other difficulties connected with Laplace's hypothesis, and many attempts have been made to overcome them. But these efforts have proved only partially successful, and for some years it has become increasingly evident that the hypothesis must be abandoned for something in better agreement with modern telescopic discoveries. The idea that the planets were formed by the condensation of rings detached from a nebulous mass is an hypothesis for which we find no warrant in the heavens. Laplace's idea of a nebular hypothesis was probably suggested by a consideration of Saturn's rings. But modern researches on tidal action tend to show that this wonderful system was not originally formed as a ring left behind by Saturn during the process of condensation from the nebulous stage. More probably the matter composing the rings was originally separated from the planet in one mass. This mass, being too close to Saturn to consolidate into a satellite—being within what is known as "Roche's limit"—was torn into fragments by the force of tidal action, and its particles were scattered round the planet in the form of a ring (or rings) as we now see it. On this view of the matter the course of events was exactly the reverse of what was supposed to have happened in Laplace's hypothesis. Instead of a ring being first formed, and then a number of small satellites from this ring, we must conclude that a mass of matter was first detached from the partially consolidated planet, and that then this mass was broken up into small fragments by the enormous tidal action of the central mass.

---

[1] *Astrophysical Journal*, March, 1900.

We see in the heavens numerous forms of nebulæ—spiral nebulæ, planetary nebulæ, etc.—but there is no really good example of a ring nebula. Those which have been termed "annular nebulæ" are most probably spiral nebulæ seen foreshortened. Of the numerous nebulæ recently discovered with the Crossley reflector at the Lick Observatory, it has been found that "a large proportion are spiral, and that practically all the spirals are lenticular or disc-shaped. Many of them are relatively very thin."[1] At one time the photographs of the great nebula in Andromeda were thought to show signs of ring formation, but Dr. Roberts, describing his photograph of this wonderful nebula, says, "That this nebula is a left-handed spiral, and not annular, as I at first suspected, cannot now be questioned; for the convolutions can be traced up to the nucleus, which resembles a small bright star at the centre of the dense surrounding nebulosity." Even the so-called "ring nebula" in Lyra, which is sometimes adduced as an example of ring formation, was found by Professor Schaeberle, of the Lick Observatory, to be "a two-branched spiral which commences at the central star, and in a clockwise direction emerges on opposite sides near the minor axis."[1] Even the apparent ring form of this nebula seems to be fictitious. Instead of being annular in shape, it appears to be a hollow spheroid, the ring representing the thickness of the shell. To any one who still persists in maintaining the hypothesis of ring formation in nebulæ, it may be said that the whole heavens are against him.

---

[1] *Publications of the Astronomical Society of the Pacific*, December 10, 1904.

It has always been difficult to imagine how rings could possibly have been formed from the parent mass, considering the extreme tenuity of the original nebula. Computing from the total mass of the bodies composing the solar system, the density of the primitive nebulous mass—supposing it extended to the orbit of Neptune—would have been almost inconceivably small. The density of atmospheric air would be millions of times greater, and how rings could be formed in such a tenuous gas has always been a serious difficulty in the discussion of Laplace's hypothesis. But there is a still more fatal objection. The original idea was that the detached "rings" would at first break up into separate masses, and that these fragments would afterwards—by their mutual attraction—consolidate into planets. But Moulton has shown by a mathematical investigation "that the tidal forces coming from the interior mass would more strongly tend to scatter the material than its gravitation would to gather it together into a planet. Consequently, a ring could not even start to condense into a planet."

---

[1] *Nature*, August 6, 1903.

Compelled therefore, as we apparently are, to abandon Laplace's nebular hypothesis in its original form, are we therefore obliged to relinquish all attempts to explain the formation of suns and solar systems from the consolidation of gaseous matter? By no means. The heavens, which are clearly against Laplace's hypothesis, are strongly in favour of a new theory, a new cosmogony, which will probably stand the test of mathematical analysis. This is the evolution of suns and systems from spiral nebulæ. Of the half-million nebulæ discovered by the Crossley reflector, a large proportion are spiral, and the study of these remarkable and interesting objects will probably form an important part of the work of future astronomers.

Laplace's original nebula was gaseous, and a gaseous spectrum shows bright lines. But the spectrum of the spiral nebulæ is *continuous*, indicating that they are partially consolidated from the gaseous condition. We can therefore easily imagine that masses might be thrown off or detached from the parent mass by the centrifugal force of the rotation. This seems much more probable than the formation of rings from a highly tenuous nebula. Photographs of spiral nebulæ show us masses in the act of being detached from the spiral branches. This

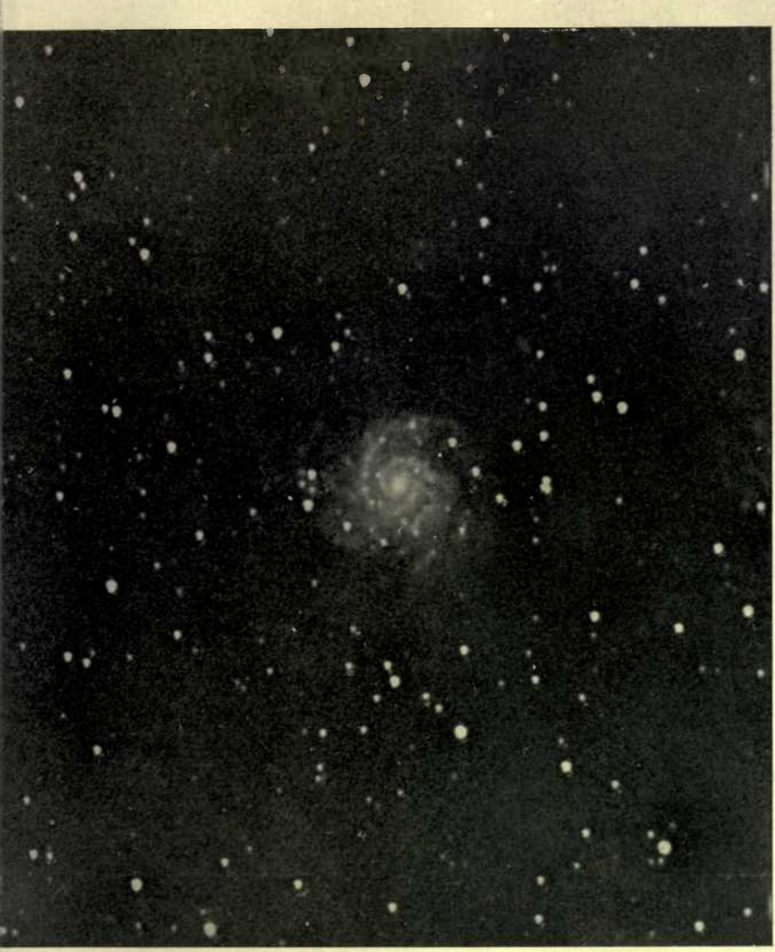

PLATE 6.—THE SPIRAL NEBULA M. 74 PISCIUM.

From a Photograph by Dr Isaac Roberts.

is particularly noticeable in the accompanying photograph, in which we see the process going on before our eyes.

The theory of the evolution of suns and solar systems from spiral nebulæ has recently been investigated mathematically by Professors T. C. Chamberlin and F. R. Moulton. This investigation consists in an attempt "to test, by an appeal to the laws of dynamics, the consistency of the ring theory with known phenomena. Contradictions were uniformly found, and in some cases the results were so conclusive as to compel us frankly to abandon it as an untenable hypothesis."[1] An outline of this new cosmogony, called by Chamberlin the "planetesimal hypothesis," and which certainly seems a great improvement on that of Laplace, may prove of interest to the general reader.

The *origin* of the nebulous mass from which the solar system is supposed to have been evolved was not considered by Laplace. He *assumed* its existence, and then proceeded to show, as he thought, how the sun and planets might have been formed from it by the consolidation of the nebulous matter in the course of ages. As we have seen, his hypothesis has broken down badly, and something else must be substituted for it if we are to retain a nebular hypothesis in any form. The origin of spiral nebulæ is, of course, unknown, but of their existence there can be no doubt. Photography has fully confirmed the discovery originally made by Lord Rosse with his giant 6-feet telescope. They are very numerous in the heavens. Professor Keeler thought that probably one-half of the nebulæ found with the Crossley reflector are spiral, and that "any small compact nebula not showing evidence of spiral structure appears exceptional." Spiral nebulæ were, of course, unknown to Laplace, and, had he known of their existence, we should probably never have heard of "ring formation."

---

[1] *Astrophysical Journal*, October, 1905.

A spiral nebula may possibly have been formed by the "grazing collision" of two solid masses, or by the near approach of two bright stars. Supposing the near approach of a large body to another of larger size, the effect on the latter body would be the production of a gigantic tide on the side turned towards the approaching body, and another tide of almost equal size on the *opposite* side. These tides would produce explosions and eruptions of nebulous matter from the interior of the star, and Moulton shows that the ejected material would assume the spiral form. This has also been shown by Herr E. J. Wilczynski, of Berlin.[1] Now, it is a remarkable feature of spiral nebulæ that the spiral branches (usually two) almost invariably issue from the central nucleus at diametrically opposite points, thus agreeing with the new hypothesis. The spiral nebulæ which we see in the heavens are, of course, constructed on a colossal scale, and probably represent a stage in the evolution of star systems rather than solar systems like ours. But the principle would be the same in both cases.

In Chamberlin's "planetesimal hypothesis" the original nebulous mass "must have spread out in the form of a relatively thin disc," and instead of being homogeneous, as in Laplace's hypothesis, "it may have had almost any degree of heterogeneity." In this theory fluid pressure, which was of fundamental importance in Laplace's hypothesis, is of minor consideration, and "no general shrinkage with loss of heat" plays any part in the evolution of planets from the parent mass.

---

[1] *Astrophysical Journal*, vol. 4 (1896), p. 98.

Moulton shows that on the new theory the resulting planets will all probably revolve round the nucleus in the same direction as the original rotation, and that the planes of their orbits "will nearly, though not exactly, coincide;" also that the orbits of the larger planets will show smaller deviations from the general plane than those of the smaller planets, like Mercury and the asteroids. This we know to be the case in the solar system. He shows that the present rotation of the sun is due to the original rotation of the mass from which it was formed, combined with the disturbance caused by the body which approached it, and that the more rapid rotation of the sun's equator is due to the same cause. He also shows that the larger the planet, "the more nearly circular in general" its orbit would be; and this also agrees with the known facts of the solar system. The orbits of the so-called "terrestrial planets" Mercury, Venus, the Earth, and Mars are, on the average, more eccentric than those of the large planets Jupiter, Saturn, Uranus, and Neptune; and those of the small minor planets between Mars and Jupiter are still more so.

With reference to the rotations of the planets on their axes, Moulton shows that these would probably be direct, that is, in the same direction as the orbital revolutions, and that the inclinations of the axes of rotation to the planes of the orbits might be different for different planets. Any well-marked deviation from the general rule might be expected in the outer planets of the system. This we see in the case of Uranus and Neptune, which have always been stumbling-blocks in Laplace's hypothesis. We should also expect, he thinks, " to find the larger planets rotating more rapidly than the smaller," as we know to be the case.

With reference to the satellites, the direction of their motion round the primary may, on the new hypothesis, be either direct or retrograde, according to circumstances. Retrograde motion might be expected in satellites very remote from their primary, and revolving in orbits of high eccentricity. This is the case with Phœbe, the recently discovered ninth satellite of Saturn. The position of the satellites of Uranus could not have been predicted by the new theory, but Moulton thinks that "they do not definitely contradict it as they do the ring theory." A satellite might also, on the new theory, revolve more rapidly round its primary than the planet rotates on its axis. This is the case with Phobos, the inner satellite of Mars, which revolves round the planet in 7 hours 39 minutes 15 seconds, while Mars' period of rotation on its axis is 24 hours 37 minutes $22\frac{2}{3}$ seconds, or over three times as long. This unusually rapid rotation of a satellite formed another objection to Laplace's hypothesis, but it seems to be consistent with the new cosmogony.

With reference to the so-called " moment of momentum " of the solar system, Professor Chamberlin has shown that the greater portion belongs to the planets, and that Jupiter alone contains about 95 per cent. of the moment of momentum of the total mass within the orbit of Saturn. This is, according to

Moulton, "an inevitable consequence of the spiral theory, but, on the contrary, the whole question of the moment of momentum is a rock on which the ring theory breaks."

According to the new cosmogony, the outer portions of the matter ejected from the original body would evidently be formed from the surface portions of the star, while the matter which followed would "come mainly from the lower depths," and would probably consist of materials of greater density. The smaller planets should therefore be cool and of high density, and the larger planets hot and of small density. This also agrees with the known facts of the solar system. The average density of Mercury, Venus, the Earth, and Mars is about $4\frac{1}{2}$ (water = 1), while the mean density of Jupiter, Saturn, Uranus, and Neptune is only 1·03, or about that of water. We know that the earth is cool, and that probably Mercury, Venus, and Mars are so also, while there is good reason to suppose that the large planets are in a highly heated condition.

On the whole, Moulton concludes that "the spiral theory is even now a good working hypothesis." It seems to explain satisfactorily all the observed phenomena upon which the ring theory was based, and many others which are in contradiction to Laplace's original hypothesis. "Nothing has yet been found which seems seriously to question its validity."

The new cosmogony will, of course, raise many very difficult questions in celestial mechanics, and will give a considerable amount of work to mathematical astronomers before it can be placed upon a satisfactory basis; but the work which has been already done by Chamberlin and Moulton shows clearly that the spiral theory is far superior to Laplace's nebular hypothesis, which should now be definitely abandoned and consigned to the limbo of unproved theories. The heavens show us thousands of spiral nebulæ which are evidently in a state of rotation round a central nucleus, but which will probably take ages before they have finally consolidated into suns and solar systems. But ages are but moments in the evolution of the stars, and we need not expect to find much evidence of rotation and consolidation during the brief span of human history. Empires rise and fall, dynasties are founded and dissolved, but the heavens move on in their silent course, and the human race will probably have perished before the universe has reached its final destiny.

INDEX

A

Absolute brightness of stars, 163, 164
Abul Wefa, 47, 88
Accadians, 10, 23
Achernar, 81
Adams, 311, 321
Adar, 12
Adonis, 17
Agathocles, 29
Aitken, 307, 323
Al-abûr, 22
Albategnius, 88
Albireo, 87
Alcor, 83
Aldebaran, 20, 82
Alderamin, 87
Alexandrian library, 35
Algenib, 87
Algol, 86, 235–237
Almach, 85
Almagest, 67, 68
Almanacs, 31
Alnilam, 83
Alnitak, 83
Alpetragus, 49
Alphard, 85
Alphecca, 86
Alpheratz, 85
Alphonsine tables, 88
Al-Sufi, 22, 79, chap. xii., 257
Altair, 25, 81
Alwaid, 87
Anaxagoras, 10, 17, 53, 59
Anaximander, 38, 58
Anaximenes, 17, 59
Andromeda nebula, 145
Anghiera, 257
Antares, 82
Antoniadi, 274, 275
"Apex," Sun's, 129, 315
Apollonius, 46, 64
Aquarius, 23
Aquila, 24
Aquilæ, Nova, 318
Arabian astronomers, 24, 47, 49, 55, 89, 108
Aratus, 8, 10, 63, 65
Archimedes, 34, 45, 53, 60, 63
Argelander, 287
Aristarchus, 37, 51, 53, 62
Aristophanes, 31
Aristotle, 16, 19, 37, 43, 54, 60, 92
Aristyllus, 62
Arzachel, 102
Assyrians, 28, 38, 39, 54, 56
Astar, 12, 18
Atlas, 24
Autolycus, 61
Auwers, 306
Auzot, 95, 97

B

Babylonian astronomers, 36, 39
Badovere, 94
Bailly, 111
Barnard, 250, 251, 266, 267
Barr, 319
Belalcacar, 27
Bellatrix, 83, 230
Belopolsky, 244, 278

Benetnasch, 83
Berenice, 21
Betelgeuse, 81
Binary stars, 121, 172, 174–177
Bode, 192
Bond, 201, 273
Book of the Dead, 20
Borelli, 105, 106
Bowyer, 322
Bradley, 97, 175
Brenner, 275, 276
Brightest stars, 66
Brightness of stars, 155–162, 194, 195, 229
Brightness, intrinsic and absolute, 163, 164
Brugsch, 31
Bullialdus, 105
Burns, 286, 322

C

Cæsar, Julius, 3, 14, 43, 107, 108
Calendars, 13
Callimachus, 21
Callippus, 15, 42, 61
Campbell, 278, 311, 323
Canis Major, 24
Canopus, 8, 22, 79
Capella, 20, 80
Capricornus, 23
Cassini, 277
Cassiopeia, 6
Castor, 174, 175, 321
Catalogue of Nebulæ, 147
Cavendish, 123
Centauri, α, 227, 240, 241, 303
Centaurus, 24
Cepheus, 6
Ceraski, 203, 320
Chaldean astronomers, 10, 17, 29, 31, 32, 44, 49
Chamberlin, 329, 330, 332, 333
Chandler, 236, 302
Chaph, 87
Chi-King, 7
Chinese annals, 6, 27, 28
Chinese astronomers, 4, 6, 15, 16, 17, 20, 24, 29, 30, 31–35, 38, 39, 44, 45, 49, 107
Chun-tsiou, 27
Cicero, 3, 16, 29, 107
Clairaut, 109, 111
Clark, 201, 245
Claudianus, 45
Clearchus, 38
Cleomedes, 41, 55, 65, 107
Clepsydras, 11, 33
Clocks, 90, 91
Clusters, globular, 148, 189, 190
„ irregular, 147–150, 189
Colours of stars, 314
Coma Berenices, 21, 145, 303
Comets, 54
Confucius, 7, 27
Conon, 21, 63
Constantinople, Council of, 3
Construction of the heavens, 130–155, 171, 179
Copernicus, 48, 55, 99–102
Corsali, 257
Cosmogony, New, chap. xxiv.
Cursa, 87
Curtis, 305, 321

D

D'Alembert, 111
Dante, 56
Dark bodies, 122, 123, 254, 255, 292–300
Darwin, Prof., 324
Davis, 279
Dawes, 273
Dee, John, 93
Deferent, 46
Delambre, 55
Democritus, 10, 44, 54, 59
De Morgan, 65
Deneb, 82
Denebola (β Leonis), 85
Denning, 267
Descartes, 104, 108
Deslandres, 278
Digges, 93

Dilgan, 20
Diogenes Laertes, 58
Diphda, 86
"Disc theory," 132, 287
Distances of the stars, 285
Doberck, 175, 176, 307, 313
Dollond, 98
Doolittle, 317
Draco, 6, 24
Draconis, α, 7, 16, 19, 54
„ 10 (*i*), 7, 54
Duns Scotus, 16

E

"Earth-shine," 38
Easton, 283, 286, 287
Eccentricity of earth's orbit, 46
Eccentrics, 46
Eclipses, 38–41
Ellerman, 276, 312
Empedocles, 10, 59
Enceladus, 97
Encke, 31
Enif, 86
Ennius, 29
Epicurus, 54
Epicycles, 46–49
Equant, 48
Equation of the centre, 46
Equulei, δ, 232, 233, 243
Equuleus, 66
Eratosthenes 10, 63, 64
Eros, 308
Etanin, 86
Euclid, 9, 62
Euctemon, 44
Eudemus, 40, 61
Eudoxus, 19, 42, 44, 60, 63
Euler, 111
Euripides, 59
External galaxies, 144
Extinction of light, 288

F

Fabry, 201
Fauth, 275
Festus Avienus, 63
Flamsteed, 160, 161
Fomalhaut, 82
Fracastor, 92
Franks, 310
Frost, 311
Furner, 322

G

"Gages," star, 133, 134, 136, 138–141, 143
Galaxy. *See* Milky Way
Galileo, 94, 100, 108
Gascoigne, 95
Gaseous nebulæ, 151
Geber, 88
Geminus, 44, 66
Generini, 95
Genesis, 3
Germinus, 55
Gill, Sir David, 252, 303
Globular clusters, 148, 189, 190
Glorioso, 93
Gnomon, 26, 61
Great Bear, 6, 7, 20
Gregorian calendar, 14
Guthnick, 272, 317

H

Hadley, 315
Hale, 276, 312, 321
Hall, Asaph, 266, 267
„ Chester More, 98
Halley, 106, 109
Halm, 318
Hamal, 85
Hanumana, 20
Hartmann, 293, 306
Hartwig, 317
Harvard Observatory, 277, 280
Heliacal risings and settings, 10
Helicon, 40
Heraclides, 48, 54, 61
Heraclitus, 16
Herculis cluster, 307

Herodotus, 17, 32, 57
Herschel, Caroline, 145, 160, 250
„ Sir John, 173, 190, 249, 251, 255, 256, 258, 259, 260, 261, 263, 264, 288
Herschel, Sir William, 97, chap. x., 274, 281, 287, 302, 303
Hesiod, 3, 9, 10
Hesperus, 9, 58
Hevelius, 91, 96, 97
Hi and Ho, 39
Hia, 11
Hieroglyphics, 9, 35
Hindoos, 4, 7, 12, 20, 24, 25, 31, 33, 38, 39, 49, 56
Hinks, 322
Hipparchus, 10, 11, 24, 30, 34, 39, 44, 46, 51, 53–56, 64, 96
"Holes" in Milky Way, 143, chap. xviii.
Homer, 3, 6, 8, 9
Hooke, 106
Horapolla, 37
Horrox, 105
Horus, 18
Hours, origin of the, 2, 3, 11
Houzeau, chap. xii., 257
Hussan-Ali, 47
Hussey, 232, 233
Huygens, 91, 107
Hyades, 6
Hydra, 24
Hyginus, 10, 21
Hypothesis, nebular, chap. xxiv.

I

Ibn Yunis, 88
Ilskhan-Olagon, 88
Incas, 27
Indians, 4, 7, 49
Insulated stars, 171
Intrinsic brightness of stars, 163, 164, 229
Irregular clusters, 147–150, 189
Istar, 12

J

Jews, 15, 18
Joshua, 17
Julianus, 99
Julian year, 14
Jupiter, 9, 16, 31

K

Kapteyn, 284, 289
Keeler, 275, 278, 329
Kepler, 37, 48, 102–104, 107, 278
Kien-siang, 45
Kirkwood, 278
Koran, 19
Koue-yu, 44
Kustner, 317

L

Lacaille, 261
Lagrange, 110
Lalande, 133, 134
Lampland, 317
Laplace, 27, 28, 108, 109, 277, 324–333
Laprey, 94
Larissa, 29
Lassell, 97
Lau, 320
Layard, 35
Lens, 91, 92
Leo, 7
Leonis, γ, 176
Le Verrier, 30
Libra, 23
Lick Observatory, 304
Limited number of visible stars, 280, 281, 282
Limiting apertures, 193
Lippershay, 94
Livy, 3
Lohse, 302
Lucifer, 9
Lunar calendar, 13

Lupus, 24
Lyra, 7, 21, 22
Lyræ, β, 228

M

Magellanic clouds, chap. xix., 288, 289
Magnitudes, star, 164, 165
Mahabharata, 18, 28, 290, 291
Maha-yuga, 56
Manilius, 6, 10, 67
Markings on moon's surface, 4
Mars, 9, 12, 13, 16, 30, 102, 103
Martianus Capella, 45
Masses of stars, 316
Ma-touan-lin, 30
Maxwell, Clerk, 277
Mayer, 101, 130, 177
Megalosaurus, 39
Menander, 3
Menelaus, 67
Menkalinan, 84
Mercury, 12, 16, 30
Merodach, 12
Meteoric stones, 19
Metius, 94
Meton, 15, 27, 60
Michell, chap. ix.
Milky Way, 7, 59, chap. v., 95, 130, 132, 133, 171, 173, 190, 191, 195-197, 223, 224, 249, 256, 281, 282, 284, 285, 288, 301, 303
Mimas, 97
Mira Ceti, 322, 323
Mirac, 86
Mirfak, 84
Mitchell, 321
Mitra, 18
Mizar, 86
Möller, 314
Moon, 16; distance of, 51, 52
Moore, 19
Motions, proper, 127
Moulton, 324, 329, 331, 333
Müller, 267
Musical notes, 43, 44

N

Nath, 84
Nebo, 12
Nebulæ, 147–150, 180–186
  „ spiral, 308, chap. xxiv.
  „ stellar, 187
Nebular hypothesis, chap. xxiv.
  „ regions, 182
Nebulous areas, 153
  „ stars, 150–153, 173
Nebus, 35
Nergal, 12
New cosmogony, chap. xxiv.
"New" stars, 318
Newcomb, 96, 201, 202, 281, 284, 286, 303, 311
Newton, Sir Isaac, 97, 98, 106–111
Nile, rising of, 13
Ninip, 12
Nova Persei, 292, 301, 309
Number of stars, chap. xiv.

O

Obliquity of ecliptic, 10, 61
Odin, 18
Offord, 279
Ophiuchi, 70, 235, 243
Oppolzer, 28
Orion, 20
  „ nebula, 145, 174, 186, 252
"Orion type" stars, 230, 311, 312
Orion's "belt," 6, 197
Osiris, 18
Ovid, 8

P

Palmer, 303
"Paradise and the Peri," 19
Parallax of stars, 124–127, 316
Parkhurst, 312
Peirce, 277
Perkins, 279
Perrine, 308, 309

Persei, Nova, 292, 301, 309
Phases of moon, 4
Philolaus, 59
Philostratus, 41
Phobos, 332
Phœbe, 220, 271, 272, 332
Phosphorus, 58
Picard, 95
Pickering, Prof. E. C., 161, 236, 265, 314
Pickering, Prof. W. H., 269
Pingré, 54
Planetarium, 45
Planetary nebulæ, 146, 147
Plato, 3, 19, 35, 60
Pleiades, 6, 17, 20, 118, 119, 148
Pliny, 4, 41, 59, 108
Plough, 20
Plummer, 307
Plutarch, 27, 29, 30, 38, 41, 54, 58, 59, 107
Pole star, 8, 84, 214
Pollux, 82, 214
Porta, 93
Posidonius, 38, 45, 53, 65
Precession of equinoxes, 55
Proclus, 55
Proctor, 276, 279
Procyon, 20, 22, 81, 195, 228, 234
Proper motions, 127
Prosneusis, 47
Ptolemy, 19, 21, 24, 28, 34, 44, 46–50, 52, 53, 66, 67, chap. v., 96, 100, chap. xii.
Pulkowa Observatory, 273
Puppis, V, 239
Pyramids, 15, 32, 57
Pythagoras, 9, 43, 58
Pytheas, 61, 107

R

Ra, 18
Radeaux, 271
Ramses, 7
Ras al-ague, 85
"Red bird," 7
Red stars, 312, 313
Reflected light, 166
Reflecting telescopes, 166–170
Regulus, 83
Reinholdus, 102
Rigel, 22, 80, 230, 231
Rig-Veda, 24
Ring nebula, 145, 326
  „ theory of Milky Way, 133
Rings of Saturn, 273–279
Ritchey, 98
Roberts, C., 275
  „ Dr. Isaac, 168, 169, 185, 222, 223, 224, 252, 281, 310, 326, 327
Roberval, 277
Roche, 326
Roemer, 101, 130
Roger Bacon, 93, 108
Rogovsky, 268
Roman astronomers, 40
Rosse, Earl of, 329
Russell, H. C., 250, 261, 262
  „ H. N., 322

S

Sacred fires, 18
Sagittarius, 23
Saros, 39
Satellites of Saturn, 269
Saturn, 12, 16, 31, 43, 114, chap. xx.
Scandinavian mythology, 2
Schaeberle, 276, 327
Scheat, 87
Schedir, 86
Schiller, 257
Schmalkalde, 17
Schmidt, 37
Scorpio, 7, 23
Scotus, 16
Seasons, 5
Secular acceleration of moon, 109, 110
Secular variation of stars, chap. xii.
See, Dr., 231, 304
Seeliger, 255, 281, 289

Seleucus, 107
Seneca, 16, 19, 33, 48
Seti I., 7
Shakspeare, 4, 154
Sidereal system, chap. xxi.
Signs of the zodiac, 23, 24
Simplicius, 61
Sirius, 5, 10, 13, 14, 20, 22, 78, 79, 117, 164, 165, 169, 170, 172, 227, 231, 232, 242, chap. xvii., 282, 283, 302
Slipher, 305
Smyth, Admiral, 84
Socrates, 16, 59
Sola, Comas, 267
Solar "apex," 315
Solstices, 5
Sosigenes, 43
Southern Cross, 6, 249
Spectacles, 92
Spectra of red stars, 312, 313, 321
Spectroscopic binaries, 244
Spheres, celestial, 24, 34
  „ crystal, 41–44
Spica, 82
Spiral nebulæ, 308, chap. xxiv.
Stadium, 66
Star clusters, 147–150, 189, 190
  „ groups, 199, 200
  „ magnitudes, 164, 165
Stars and nebulæ, 187, 188, 189
Stebbins, 323
Steinheil, 201
Stellar brightness, chap. xv.
  „ evolution, chap. xxiv.
  „ nebulæ, 187
  „ universe, chap. xxi.
Stockwell, 304
Strabo, 27, 92
Stroobant, 279
Struve, 273, 287
Sulpicius Gallus, 40
Sun, 16; distance of, 51; sun's apex, 129, 315
Sundials, 32
Sun's motion in space, 127–130, 177
Sun's parallax, 308, 317
Sun-spots, 30, 160
Sun's stellar magnitude, chap. xi., 226
Suriya-siddhanta, 45, 50
Syene, 27

T

Tacitus, 3
Tai-pi, 12
Talmud, 45, 93
Tamerlane, 89
Tammuz, 17
Tatius, 10
Taurus, 7
Tchang-tse-sin, 45
Tcheou-kong, 6, 27
Tcheou-li, 29, 33
Tcheou-pey, 34
Tchong-kang, 28
Telescopes, 93–98, 166–170
Temporary stars, 318
"Terminator" of moon, 51
Thales, 16, 28, 57
Themis, 270, 271, 272
Theon, 10, 55, 59
Thor, 18
Timocharis, 55, 62
Torsion balance, 123
"Trifid" nebula, 314
Trouvelot, 251, 279
Tubes, 92, 93
Tycho Brahé, 47, 48, 56, 89, 91, 96, 100, 101, 103, 105

U

Ulugh Beigh, 89
Ursa Major, 24
  „ Minor, 24

V

Variable stars, 127, 154, 316
"Variation," 47
Variation, secular, chap. xii.

Varuna, 18
Vedas, 7
Vega, 25, 80
Velocity of stars, 311
Venus, 8, 9, 12, 16
Very, 301
Vesta, 18
Vindemiatrix, 87
Virgil, 19, 56
Virginis, γ, 176, 177, 233, 244
Virgo, 23
Vishnu, 18
Visible stars, chap. xxi.
  „ universe, chap. xxi.
Vogel, 276, 306

W

Walther, 21
Waning moon, 4
Waxing moon, 4
Weber, 267
Wezen, 84
Wilczynski, 330
Williams, Stanley, 267, 279
Wilson, H. C., 302, 315
Wolf, Max, 253, 309, 317
Wollaston, 123, 201
Wren, 106
Wright, 303
Wright of Durham, 132, 154, 277

Y

Yao, 6, 20, 26, 54
Year, 5
"Year books," 31
Yendell, 302
Young, Prof., 201, 267

Z

Zenophon, 3
Zoan, 3
Zodiac, signs of, 23, 24

THE END

PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, LONDON AND BECCLES.

C
W

CHATTO & WINDUS'S
POPULAR TWO-SHILLING NOVELS
BY THE BEST AUTHORS.

BOUND IN PICTURE CLOTH, FLAT BACKS.

BY EDWIN LESTER ARNOLD.
The Constable of St. Nicholas.

BY SIR WALTER BESANT.
St. Katherine's by the Tower.
The Rebel Queen.

BY HAROLD BINDLOSS.
Ainslie's Ju-ju.

BY McD. BODKIN, K.C.
Dora Myrl, Lady Detective.

BY DICK DONOVAN.
The Man-hunter.
Tales of Terror.
Vincent Trill, Detective.
Dark Deeds. | Wanted!
The Man from Manchester.
Mystery of Jamaica Terrace.

BY GEORGE MANVILLE FENN.
A Crimson Crime.

BY PAUL GAULOT.
The Red Shirts.

BY MAJOR A. GRIFFITHS.
No. 99; and Blue Blood.

BY BRET HARTE.
Luck of Roaring Camp; and SensationNovelsCondensed.
In a Hollow of the Hills.
A Sappho of Green Springs.
Colonel Starbottle's Client.
A Protégée of Jack Hamlin's.
Sally Dows.

BY OWEN HALL.
The Track of a Storm.

BY HEADON HILL.
Zambra, the Detective.

BY FERGUS HUME.
The Lady from Nowhere.

BY EDMUND MITCHELL.
Plotters of Paris.
The Temple of Death.
Towards the Eternal Snows.

BY BERTRAM MITFORD.
The Luck of Gerard Ridgeley.
The King's Assegai.

BY J. E. MUDDOCK.
Maid Marian & Robin Hood.

BY D. CHRISTIE MURRAY.
His Own Ghost.

BY OUIDA.
Syrlin.
The Waters of Edera.

BY JAMES PAYN.
A Modern Dick Whittington.

BY DORA RUSSELL.
A Country Sweetheart.
The Drift of Fate.

BY G. R. SIMS.
In London's Heart.
Rogues and Vagabonds.

BY FRANK STOCKTON.
The Young Master of Hyson Hall.

BY SUNDOWNER.
The Tale of the Serpent.

BY SARAH TYTLER.
Citoyenne Jacqueline.

BY ALLEN UPWARD.
The Queen against Owen.

BY FLORENCE WARDEN.
Joan, the Curate.

BY BYRON WEBBER.
Sport and Spangles.

BY JOHN STRANGE WINTER.
Cavalry Life; and Regimental Legends.

BY LOUIS ZANGWILL.
A NineteenthCentury Miracle.

BOUND IN PICTURE BOARDS.

BY MRS. ALEXANDER.
Maid, Wife, or Widow?
Valerie's Fate.
Blind Fate.
A Life Interest.
Mona's Choice.
By Woman's Wit.

BY GRANT ALLEN.
Strange Stories.
Philistia.
Babylon.
The Beckoning Hand.
In All Shades.
For Maimie's Sake.
The Devil's Die.
This Mortal Coil.
The Tents of Shem.
The Great Taboo.
Dumaresq's Daughter.
The Duchess of Powysland.
Blood-Royal.
Ivan Greet's Masterpiece.
The Scallywag.
At Market Value.
Under Sealed Orders.

BY EDWIN LESTER ARNOLD.
Phra the Phœnician.

BY FRANK BARRETT.
A Recoiling Vengeance.
For Love and Honour.
John Ford; & His Helpmate.
Honest Davie.
A Prodigal's Progress.
Folly Morrison.
Lieutenant Barnabas.
Found Guilty.
Fettered for Life.
Between Life and Death.
The Sin of Olga Zassoulich.
Little Lady Linton.
Woman of the Iron Bracelets.
The Harding Scandal.
A Missing Witness.

BY BESANT AND RICE.
Ready-Money Mortiboy.
With Harp and Crown.
This Son of Vulcan.
My Little Girl.
The Case of Mr. Lucraft.
The Golden Butterfly.
By Celia's Arbour.
The Monks of Thelema.
'Twas in Trafalgar's Bay.
The Seamy Side.
The Ten Years' Tenant.
The Chaplain of the Fleet.

BY WALTER BESANT.
All Sorts & Conditions of Men.
The Captains' Room.
All in a Garden Fair.
Dorothy Forster.
Uncle Jack.
Children of Gibeon.
World went very well then.
Herr Paulus.
For Faith and Freedom.
To Call her Mine.
The Bell of St. Paul's.
The Holy Rose.
Armorel of Lyonesse.
St. Katherine's by the Tower.
The Ivory Gate.
Verbena Camellia Stephanotis
The Rebel Queen.
Beyond the Dreams of Avarice.
The Revolt of Man.
In Deacon's Orders.
The Master Craftsman.
The City of Refuge.

BY AMBROSE BIERCE.
In the Midst of Life.

BY FREDERICK BOYLE.
Camp Notes. | Savage Life.
Chronicles of No-Man's Land.

London: CHATTO & WINDUS, 111 *St. Martin's Lane, W.C.*

BY ROBERT BUCHANAN.

The Shadow of the Sword.
A Child of Nature.
God and the Man.
Annan Water.
The New Abelard.
The Martyrdom of Madeline.
Love Me for Ever.
Matt: a Story of a Caravan.
Foxglove Manor.
The Master of the Mine.
The Heir of Linne.
Woman and the Man.
Rachel Dene.
Lady Kilpatrick.

BY BUCHANAN & MURRAY.

The Charlatan.

BY HALL CAINE.

The Shadow of a Crime.
A Son of Hagar.
The Deemster.

BY COMMANDER CAMERON.

Cruise of the 'Black Prince.'

BY AUSTIN CLARE.

For the Love of a Lass.

BY MRS. ARCHER CLIVE.

Paul Ferroll.
Why Paul Ferroll Killed Wife

BY MACLAREN COBBAN.

The Cure of Souls.
The Red Sultan.

BY C. ALLSTON COLLINS.

The Bar Sinister.

BY WILKIE COLLINS.

Armadale. | After Dark.
A Rogue's Life.
Hide and Seek.
The Dead Secret.
No Name. | Antonina.
Basil. | Queen of Hearts.
My Miscellanies.
The Woman in White.
The Moonstone.
Man and Wife.
Poor Miss Finch.
Miss or Mrs.?
The New Magdalen.
The Frozen Deep.
The Law and the Lady.
The Two Destinies.
The Haunted Hotel.
The Fallen Leaves.
Jezebel's Daughter.
The Black Robe.
Heart and Science.
'I say No.' | Blind Love.
The Evil Genius.
Little Novels.
The Legacy of Cain.

BY M. J. COLQUHOUN.

Every Inch a Soldier.

BY C. EGBERT CRADDOCK.

The Prophet of the Great Smoky Mountains.

BY MORTIMER AND F. COLLINS.

Sweet Anne Page.
Transmigration.
From Midnight to Midnight.
A Fight with Fortune.
Sweet and Twenty.
Frances.
The Village Comedy.
You Play Me False.
Blacksmith and Scholar.

BY MATT CRIM.

Adventures of a Fair Rebel.

BY B. M. CROKER.

Pretty Miss Neville.
Proper Pride. | 'To Let.'
A Bird of Passage.
Diana Barrington.
A Family Likeness.
Village Tales and Jungle Tragedies.
Two Masters. | Mr. Jervis.
The Real Lady Hilda.
Married or Single?
Interference. | A Third Person.

BY ALPHONSE DAUDET.

The Evangelist.

BY JAMES DE MILLE.

A Strange Manuscript found in a Copper Cylinder.

BY DICK DONOVAN.

The Man-hunter.
Caught at Last!
Tracked and Taken.
Who Poisoned Hetty Duncan?
The Man from Manchester.
A Detective's Triumphs.
In the Grip of the Law.
Wanted! | Link by Link.
From Information Received.
Tracked to Doom.
Suspicion Aroused.
Riddles Read.
Mystery of Jamaica Terrace.
The Chronicles of Michael Danevitch.

BY MRS. ANNIE EDWARDES.

A Point of Honour.
Archie Lovell.

BY EDWARD EGGLESTON.

Roxy.

BY G. MANVILLE FENN.

The New Mistress.
Witness to the Deed.
The Tiger Lily,
The White Virgin.

BY PERCY FITZGERALD.

Bella Donna. | Polly.
The Second Mrs. Tillotson.
Seventy-five Brooke Street.
Never Forgotten.
The Lady of Brantome.
Fatal Zero.

BY PERCY FITZGERALD, &C.

Strange Secrets.

BY R. E. FRANCILLON.

Olympia. | One by One.
Queen Cophetua.
A Real Queen.
King or Knave.
Romances of the Law.
Ropes of Sand.
A Dog and his Shadow.

BY HAROLD FREDERIC.

Seth's Brother's Wife.
The Lawton Girl.

PREFACED BY BARTLE FRERE.

Pandurang Hàri.

BY CHARLES GIBBON.

Robin Gray.
For Lack of Gold.
What will the World Say?
In Honour Bound.
In Love and War.
For the King. | Fancy Free.
Queen of the Meadow.
In Pastures Green.
The Flower of the Forest.
A Heart's Problem.
The Braes of Yarrow.
The Golden Shaft.
Of High Degree.
The Dead Heart.
By Mead and Stream.
Heart's Delight.
Loving a Dream.
A Hard Knot. | Blood-Money

BY WILLIAM GILBERT.

James Duke, Costermonger.

BY ERNEST GLANVILLE.

The Lost Heiress.
The Fossicker.
A Fair Colonist.

BY REV. S. BARING GOULD.

Eve. | Red Spider.

BY ANDREW HALLIDAY.

Every-Day Papers.

BY THOMAS HARDY.

Under the Greenwood Tree.

BY BRET HARTE.

An Heiress of Red Dog.
The Luck of Roaring Camp.
Californian Stories.
Gabriel Conroy.
Flip. | Maruja.
A Phyllis of the Sierras.
A Waif of the Plains.
A Ward of the Golden Gate.

BY JULIAN HAWTHORNE.

Garth. | Ellice Quentin.
Dust. | Fortune's Fool.
Beatrix Randolph.
Miss Cadogna.
Love—or a Name.
David Poindexter's Disappearance.
The Spectre of the Camera.

BY SIR ARTHUR HELPS.
Ivan de Biron.

BY G. A. HENTY.
Rujub, the Juggler.

BY HEADON HILL.
Zambra, the Detective.

BY JOHN HILL.
Treason-Felony.

BY MRS. CASHEL HOEY.
The Lover's Creed.

BY MRS. HUNGERFORD.
In Durance Vile.
A Maiden all Forlorn.
A Mental Struggle.
Marvel.
A Modern Circe.
Lady Verner's Flight.
The Red-House Mystery.
The Three Graces.
An Unsatisfactory Lover.
Lady Patty.
Nora Creina.
The Professor's Experiment.
April's Lady.
Peter's Wife.

BY MRS. ALFRED HUNT.
The Leaden Casket.
Self-Condemned.
That Other Person.

BY MARK KERSHAW.
Colonial Facts and Fictions.

BY R. ASHE KING.
A Drawn Game.
'The Wearing of the Green.'
Passion's Slave.
Bell Barry.

BY EDMOND LEPELLETIER.
Madame Sans-Gêne.

BY JOHN LEYS.
The Lindsays.

BY E. LYNN LINTON.
Patricia Kemball.
Atonement of Leam Dundas.
The World Well Lost.
Under which Lord?
With a Silken Thread.
The Rebel of the Family.
'My Love!'
Ione.
Paston Carew.
Sowing the Wind.
The One Too Many.
Dulcie Everton.

BY HENRY W. LUCY.
Gideon Fleyce.

BY JUSTIN McCARTHY.
Dear Lady Disdain.
The Waterdale Neighbours.
My Enemy's Daughter.
A Fair Saxon.
Linley Rochford.
Miss Misanthrope.
Donna Quixote.
The Comet of a Season.
Maid of Athens.
Camiola: Girl with a Fortune.
The Dictator.
Red Diamonds.
The Riddle Ring.

BY HUGH MACCOLL.
Mr. Stranger's Sealed Packet.

BY GEORGE MACDONALD.
Heather and Snow.

BY MRS. MACDONELL.
Quaker Cousins.

BY W. H. MALLOCK.
The New Republic.

BY J. MASTERMAN.
Half-a-Dozen Daughters.

BY BRANDER MATTHEWS.
A Secret of the Sea.

BY L. T. MEADE.
A Soldier of Fortune.

BY LEONARD MERRICK.
The Man who was Good.

BY MRS. MOLESWORTH.
Hathercourt Rectory.

BY J. E. MUDDOCK.
Stories Weird and Wonderful.
The Dead Man's Secret.
From the Bosom of the Deep.

BY D. CHRISTIE MURRAY.
A Life's Atonement.
Joseph's Coat.
Val Strange.
A Model Father.
Coals of Fire.
Hearts.
By the Gate of the Sea.
The Way of the World.
A Bit of Human Nature.
First Person Singular.
Cynic Fortune.
Old Blazer's Hero.
Bob Martin's Little Girl.
Time's Revenges.
A Wasted Crime.
In Direst Peril.
Mount Despair.
A Capful o' Nails.

BY D. CHRISTIE MURRAY AND HENRY HERMAN.
One Traveller Returns.
Paul Jones's Alias.
The Bishops' Bible.

BY HUME NISBET.
'Bail Up!'
Dr. Bernard St. Vincent.

BY W. E. NORRIS.
Saint Ann's. | Billy Bellew.

BY GEORGES OHNET.
Doctor Rameau.
A Last Love. | A Weird Gift.

BY MRS. OLIPHANT.
Whiteladies.
The Primrose Path.
Greatest Heiress in England.

BY OUIDA.
Held in Bondage.
Strathmore.
Chandos.
Under Two Flags.
Idalia.
Cecil Castlemaine's Gage.
Tricotrin.
Puck.
Folle Farine.
A Dog of Flanders.
Pascarèl.
Signa.
In a Winter City.
Ariadnê.
Moths.
Friendship.
Pipistrello.
Bimbi.
In Maremma.
Wanda.
Frescoes.
Princess Napraxine.
Two Little Wooden Shoes.
A Village Commune.
Othmar.
Guilderoy.
Ruffino.
Syrlin.
Santa Barbara.
Two Offenders.
Wisdom, Wit, and Pathos.

BY MARGARET AGNES PAUL.
Gentle and Simple.

BY JAMES PAYN.
Lost Sir Massingberd.
A Perfect Treasure.
Bentinck's Tutor.
Murphy's Master.
A County Family.
At Her Mercy.
A Woman's Vengeance.
Cecil's Tryst.
The Clyffards of Clyffe.
The Family Scapegrace.
The Foster Brothers.
The Best of Husbands.
Found Dead.
Walter's Word. | Halves.
Fallen Fortunes.
What He Cost Her.
Humorous Stories.
Gwendoline's Harvest.
Like Father, Like Son.

JAMES PAYN—*continued.*
A Marine Residence.
Married Beneath Him.
Mirk Abbey.
Not Wooed, but Won.
£200 Reward.
Less Black than we're Painted
By Proxy.
High Spirits.
Under One Roof.
Carlyon's Year.
A Confidential Agent.
Some Private Views.
A Grape from a Thorn.
From Exile.
Kit: a Memory.
For Cash Only.
The Canon's Ward.
The Talk of the Town.
Holiday Tasks.
Glow-worm Tales.
The Mystery of Mirbridge.
The Burnt Million.
The Word and the Will.
A Prince of the Blood.
Sunny Stories.
A Trying Patient.

BY MRS. CAMPBELL PRAED.
The Romance of a Station.
The Soul of Countess Adrian.
Outlaw and Lawmaker.
Christina Chard.
Mrs. Tregaskiss.

BY RICHARD PRYCE.
Miss Maxwell's Affections.

BY CHARLES READE.
It is Never Too Late to Mend.
Hard Cash.
Peg Woffington.
Christie Johnstone.
Griffith Gaunt.
Put Yourself in His Place.
The Double Marriage.
Love Me Little, Love Me Long.
Foul Play.
The Cloister and the Hearth.
The Course of True Love.
The Autobiography of a Thief.
A Terrible Temptation.
The Wandering Heir.
A Simpleton.
A Woman-Hater.
Singleheart and Doubleface.
Good Stories of Man and other Animals.
The Jilt.
A Perilous Secret.
Readiana.

BY MRS. J. H. RIDDELL.
Her Mother's Darling.
The Uninhabited House.
Weird Stories.
Fairy Water.
Prince Wales's Garden Party.
Mystery in Palace Gardens.
Idle Tales.

BY F. W. ROBINSON.
Women are Strange.
The Hands of Justice.
The Woman in the Dark.

BY DORA RUSSELL.
A Country Sweetheart.

BY W. CLARK RUSSELL.
Round the Galley Fire.
On the Fo'k'sle Head.
In the Middle Watch.
A Voyage to the Cape.
A Book for the Hammock.
Mystery of the 'Ocean Star.'
Romance of Jenny Harlowe.
An Ocean Tragedy.
My Shipmate Louise.
Alone on a Wide Wide Sea.
The Phantom Death.
The Good Ship 'Mohock.'
Is he the Man? | Heart of Oak.
The Convict Ship.
The Tale of the Ten.
The Last Entry.

BY ALAN ST. AUBYN.
A Fellow of Trinity.
The Junior Dean.
The Master of St. Benedict's.
To his Own Master.
Orchard Damerel.
In the Face of the World.
The Tremlett Diamonds.

BY GEORGE AUGUSTUS SALA.
Gaslight and Daylight.

BY GEORGE R. SIMS.
The Ring o' Bells.
Mary Jane's Memoirs.
Mary Jane Married.
Tales of To-day.
Dramas of Life.
Tinkletop's Crime.
Zeph: a Circus Story.
My Two Wives.
Memoirs of a Landlady.
Scenes from the Show.
The Ten Commandments.
Dagonet Abroad.
Rogues and Vagabonds.

BY T. W. SPEIGHT.
The Mysteries of Heron Dyke.
The Golden Hoop.
By Devious Ways.
Hoodwinked. | Back to Life.
The Loudwater Tragedy.
Burgo's Romance.
Quittance in Full.
A Husband from the Sea.

BY R. A. STERNDALE.
The Afghan Knife.

BY R. LOUIS STEVENSON.
New Arabian Nights.

BY WALTER THORNBURY.
Tales for the Marines.

BY ANTHONY TROLLOPE.
The Way We Live Now.
Mr. Scarborough's Family.
The Golden Lion of Granpère.
The American Senator.
Frau Frohmann.
Marion Fay.
Kept in the Dark.
The Land-Leaguers.

BY FRANCES E. TROLLOPE.
Anne Furness.
Mabel's Progress.
Like Ships upon the Sea.

BY T. ADOLPHUS TROLLOPE.
Diamond Cut Diamond.

BY MARK TWAIN.
Tom Sawyer.
The Stolen White Elephant.
Pleasure Trip on Continent.
The Gilded Age.
Huckleberry Finn.
Life on the Mississippi.
Mark Twain's Sketches.
The £1,000,000 Bank-note.

BY SARAH TYTLER.
Noblesse Oblige.
The Huguenot Family.
What She Came Through.
Beauty and the Beast.
The Bride's Pass.
Saint Mungo's City.
Disappeared.
Lady Bell.
Buried Diamonds.
The Blackhall Ghosts.

BY C. C. FRASER-TYTLER.
Mistress Judith.

BY ALLEN UPWARD.
The Queen against Owen.

BY ARTEMUS WARD.
Artemus Ward Complete.

BY WILLIAM WESTALL.
Trust-Money.

BY MRS. F. H. WILLIAMSON.
A Child Widow.

BY J. S. WINTER.
Cavalry Life.
Regimental Legends.

BY H. F. WOOD.
Passenger from Scotland Yard.
Englishman of the Rue Cain.

106355 Astron.
G

Author Gore, J. Ellard

Title Astronomical essays, historical and descriptive.

UNIVERSITY OF TORONTO
LIBRARY

Do not
remove
the card
from this
Pocket.

Acme Library Card Pocket
Under Pat. "Ref. Index File."
Made by LIBRARY BUREAU